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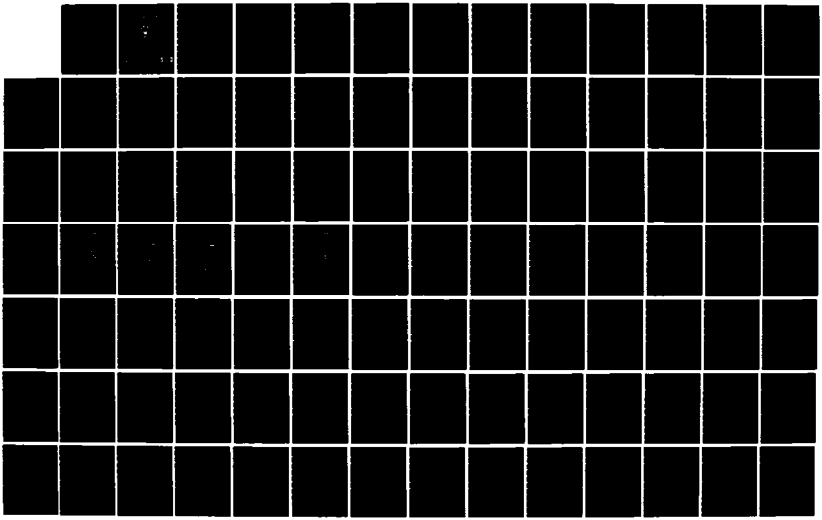

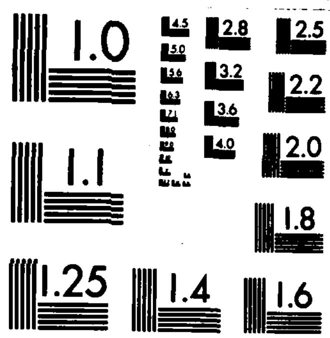
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THESIS

A STUDY OF THE WORLD'S NAVAL SURFACE-TO-AIR MISSILE DEFENSE SYSTEMS

by

Sukij Saraparung

December 1984

Thesis Advisor: Robert E. Ball

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The shipborne surface-to-air missile (SAM) system of the US Navy, French Navy, Royal Navy, Italian Navy, Canadian Navy, Israeli Navy, and Soviet Navy are examined. For each SAM system, the details of the physical make-up, the target detection and tracking, the missile guidance, the warhead, and the missile performance are presented. Finally, a study of the shipborne air defense used by the Royal Navy in the Falklands Conflict in the Spring of 1982 is made. Keywords include: -

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A Study of the World's Naval Surface-to-Air Missile Defense Systems

by

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Lieutenant Junior Grade, Royal Thai Navy
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Submitted in partial fulfillment of the requirements for the degree of

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ABSTRACT

The shipborne surface-to-air missile (SAM) systems of the US Navy, French Navy, Royal Navy, Italian Navy, Canadian Navy, Israeli Navy, and Soviet Navy are examined. For each SAM system, the details of the physical make-up, the target detection and tracking, the missile guidance, the warhead, and the missile performance are presented. Finally, a study of the shipborne air defense used by the Royal Navy in the Falklands Conflict in the Spring of 1982 is made.

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1. Noise Figure F_n

The noise figure is a function of a type of receiver, and Fig. 2.3 [Ref. 2] gives a means of estimating F_n.

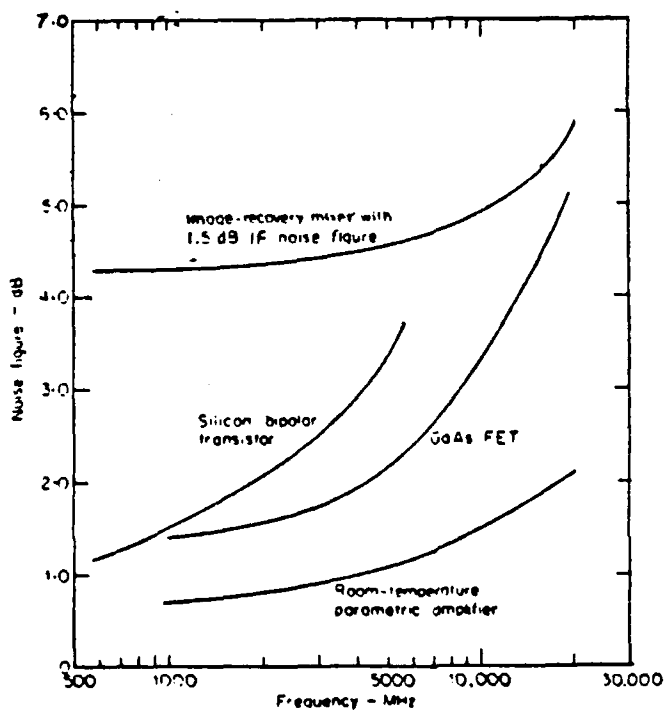

Figure 2.3 Noise Figures of Typical Microwave Receiver Front Ends as a Function of Frequency (Bell, Ref. 2).

2. Minimum Signal-to-Noise Ratio

The minimum value of (S_o/N_o) is a trade-off between missing true signals on the one hand and interpreting noise as a true signal on the other. The measure of noise being interpreted as a signal is given by the false alarm rate. Guidance figures for design relating the probability of detection, the probability of false alarm and the

$$F = \frac{\text{noise out practical receiver}}{\text{noise out of ideal receiver at std temp } T_o}$$

or

$$F_n = N_o/(kT_oB_nG_a) \tag{2.13}$$

where

N_o = noise output from receiver

G_a = available gain

k = Boltzmann's constant = 1.38×10^{-23} J/deg.

T_o = 290 degree Kelvin

B_n = receiver bandwidth

The available gain G_a is the ratio of the signal out, S_o, to the signal in, S_i, and kT_oB_n is the input noise N_i in an ideal receiver. Thus,

$$F_n = \frac{S_i/N_i}{S_o/N_o} \tag{2.14}$$

Rearranging eq. 2.14, the input signal may be expressed as

$$S_i = kT_oB_nF_nS_o/N_o \tag{2.15}$$

If the minimum detectable signal S_{min} is that value of S_i corresponding to the minimum ratio of output (of the IF amplifier) signal-to-noise ratio $(S_o/N_o)_{min}$ necessary for detection, then

$$S_{min} = kT_oB_nF_n(S_o/N_o)_{min} \tag{2.16}$$

For many radar applications this assumption is satifactory.

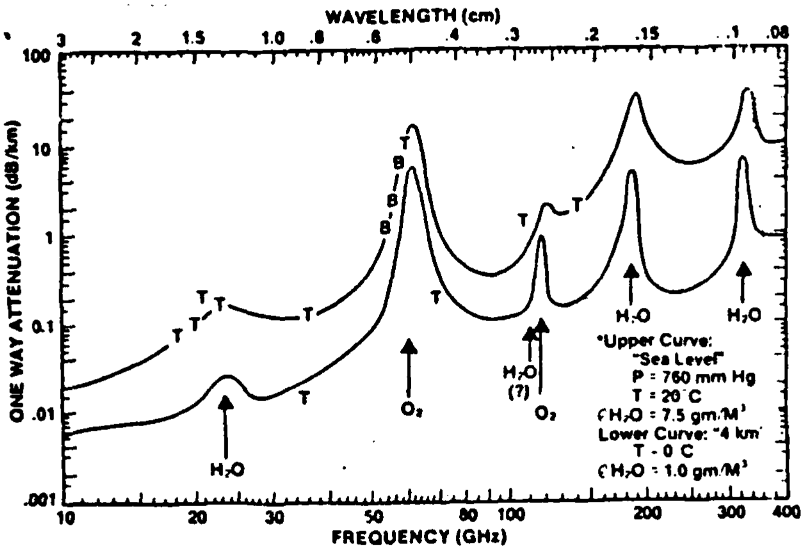

Figure 2.2 Attenuation for Horizontal Propagation (Cooper, Ref. 3).

generate any excess noise, there would still exist an unavoidable component of noise generated by the thermal motion of the conduction of electrons in the receiver input stages. This is called "thermal noise", and is directly proportional to the temperature of the ohmic portions of the circuit and the receiver bandwidth [Ref. 2]. The available thermal-noise power generated by a receiver of bandwidth B at a temperature T (degrees Kelvin) is equal to

Available thermal-noise power = kTB

No matter whether the noise is generated by a thermal mechanism or by some other mechanism, the total noise at the output of the receiver is the thermal-noise power obtained from an ideal receiver multiplied by a factor called the noise figure. The noise figure, F_n, of a receiver is defined by the equation

with pulse integration, the idealized radar equation becomes

$$P_r = \frac{P_t(A_e)^2 \sigma n^{3/4}}{4\pi R^4 \lambda^2} \qquad (2.11)$$

2. System Losses

There are many sources of power loss in the echo, and these losses reduce the energy of both the transmitted and the received signals. The overall loss is called the system loss and is the sum of all the losses. If the effect of the system loss is included in the radar equation, the equation will give more accurate picture of practical achievable ranges. A system loss factor, Ls, is replaced in the denominator of eq. 2.11, giving

$$P_r = \frac{P_t(A_e)^2 \sigma n^{3/4}}{4\pi R^4 \lambda^2 Ls} \qquad (2.12)$$

where

Ls = system loss (greater than unity)

Atmospheric attenuation of the echo can be approximated from Fig. 2.2 [Ref. 3].

B. MINIMUM SIGNAL DETECTION

Noise is the important factor limiting receiver sensitivity. It is unwanted electromagnetic energy which interferes with the ability of the receiver to detect the echo. It may originate within the receiver itself, or it may enter via the receiving antenna along with the echo. If the radar were to operate in a perfectly noise-free environment so that no external sources of noise accompanied the echo, and if the receiver itself were so perfect that it did not

The improvement with an ideal integrator would be n; however, actual practice gives something less than n [Ref. 1], and Fig. 2.1 shows the signal improvement factor versus several n, number of pulses

According to Fig. 2.1, the data fall midway between $\sqrt{n}$ and n on a log plot. A good design approximation would be [Ref. 2]

$$\log(nE_i) = \frac{1}{2}(\log n + \log n^{1/2}) = \frac{3}{4}\log n \qquad (2.9)$$

or

$$nE_i = n^{3/4} \qquad (2.10)$$

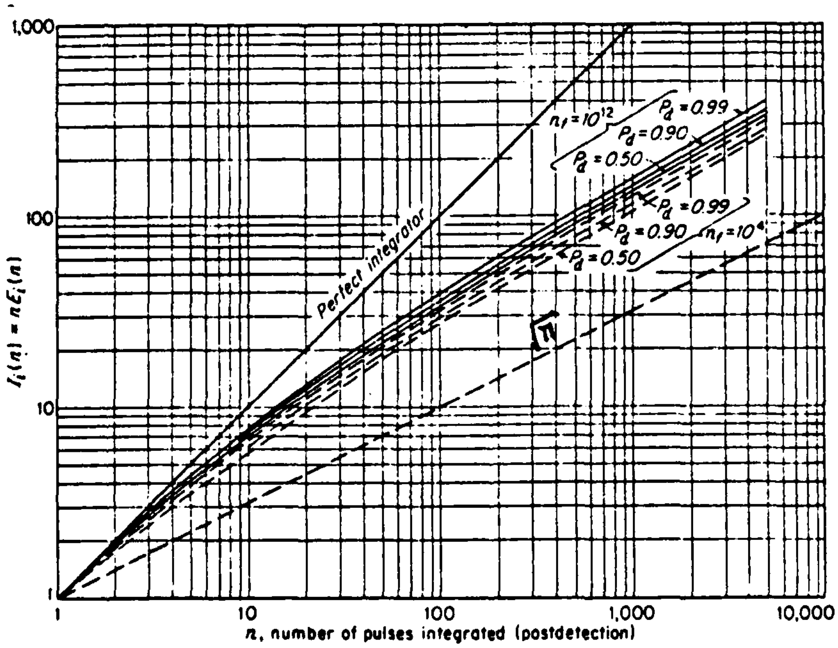

Figure 2.1 Integration Improvement Factor (Skolnik, Ref. 1).

1. Integration of Radar Pulses

The process of summing all the radar echo pulses for the purpose of improving detection is called "integration". In any radar system, the transmitter emits many pulses during the time the antenna is pointing at a target, and many echoes are received. The succession of pulses transmitted and received is called "a pulse train". If the energy in the echoes from the single pulses in a train is added, the integrated value should be the sum of all the signals in the train. Integration before the detection is called "predetection", or "coherent", integration. The integration after the detector is called "postdetector", or "noncoherent", integration. In predetection integration, the signals must be stored and added in phase before detection.

If n pulses, all of the same signal-to-noise ratio, were integrated by an ideal integrator, the resultant signal-to-noise (power) ratio would be exactly n times that of a single pulse. If the same n pulses were integrated by an ideal postdetection integrator, the resultant signal-to-noise ratio would be less than n times that of a single pulse. This loss in integration efficiency is caused by the nonlinear action of the second detector, which converts some of the signal energy to noise energy in the rectification process. The improvement in the signal-to-noise ratio when n pulses are integrated is nE_i, which is given by

$$nE_i = \frac{(S/N)_l}{(S/N)_n} \tag{2.8}$$

where

n = number of pulses integrated

$(S/N)_l$ = value of signal-to-noise ratio of a single pulse

$(S/N)_n$ = value of signal-to-noise ratio of n pulses

section σ. Thus, the power density of the target echo at the radar is given by

$$\text{Power density of echo signal at radar} = \frac{P_t G}{4\pi R^2} \frac{\sigma}{4\pi R^2} \quad (2.3)$$

If the effective area of the receiving antenna is denoted A_e, the power P_r received by the radar is

$$P_r = \frac{P_t G}{4\pi R^2} \frac{\sigma}{4\pi R^2} A_e = \frac{P_t G A_e \sigma}{(4\pi)^2 R^4} \quad (2.4)$$

Antenna theory gives the relationship between the transmitting gain and the effective receiving area of an antenna as

$$G = \frac{4\pi A_e}{\lambda^2} \quad (2.5)$$

The relationship between the effective area and actual antenna area is

$$A_e = A\rho \quad (2.6)$$

where

ρ = antenna efficiency

A = antenna area

Therefore,

$$P_r = \frac{P_t (A_e)^2 \sigma}{4\pi \lambda^2 R^4} \quad (2.7)$$

This is an idealized expression and does not account for losses or the cumulative effect of multiple pulses returning to the receiver.

II. TARGET DETECTION AND MISSILE GUIDANCE

In order to make a comparison between the capabilities of the various naval missile systems, some fundamental radar concepts and equations and missile guidance and navigation concepts must be presented.

A. THE RADAR RANGE EQUATION

An isentropic antenna is one that radiates power in all directions equally. If the power of the radar transmitter is denoted by P_t, the power density (watts per unit area) at a distance R from the radar is equal to the transmitter power divided by the surface area $4\pi R^2$ of an imaginary sphere of radius R, or

$$\text{Power density from isentropic antenna} = \frac{P_t}{4\pi R^2} \qquad (2.1)$$

Since radars employ directive antenna to direct the radiated power P_t into some particular direction, the gain G of an antenna is a ratio of the increased power from a directive antenna as compared to that of an isentropic antenna. Therefore, the power density from a directive antenna can be expressed as

$$\text{Power density from directive antenna} = \frac{P_t G}{4\pi R^2} \qquad (2.2)$$

This is the power density which arrives at the target at the range R. The measure of the amount of incident power intercepted by the target and reradiated back in the direction of the monostatic radar receiver is denoted as the radar cross

I. INTRODUCTION

The world's shipborne surface-to-air missiles (SAMs) can be divided into three distinct classes; the long-range missiles, the medium-range missiles, and the short-range/ very short range missiles. However, in other circumstances the SAMs might be divided into two types of defense systems; the area defense system and the point defense system.

In general, the SAMs are a powerful weapon both in offensive and defensive tactics. The major reason for using a shipborne surface-to-air missile is to kill aerial targets prior to their attack. The latest event in which SAMs were used is the Falklands Conflict - the "classic" limited war - between England and Argentina in the South Atlantic in the Spring of 1982. Several types of Royal Navy SAMs were used against low flying Argentinian aircraft and missiles. Most modern ships have been fitted with either long range and medium range missiles, long range and short range missiles, or medium range and short range missiles, depending upon the ship class. This thesis examine the capabilities of the SAMs of the U.S. Navy, the French Navy, the Royal Navy, the Italian Navy, the Israeli Navy, the Canadian Navy, and the Soviet Navy. The examination consists of determining the physical description of each system, the propulsion features, the warhead features, the target detection and tracking features, the missile guidance and navigation features, and the performance or system effectiveness. The examination is based totally on unclassified information that has appeared in several publications, such as Jane's, Aviation Week & Space Technology, and the Naval Institute Press.

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LIST OF FIGURES

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signal-to-noise ratio of a ideal receiver are given in Fig. 2.4 [Ref. 1].

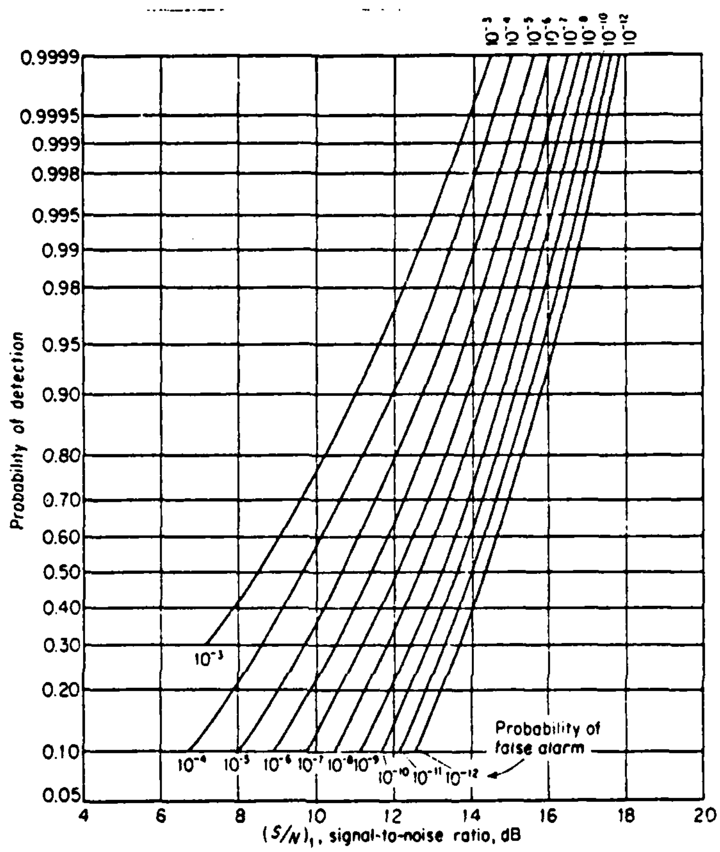

Figure 2.4 Probability of Detection, False Alarm as a Function of the Signal-to-Noise Ratio (Skolnik, Ref. 1)

3. Example

The minimum signal power that can be detected can be calculated from eq. 2.16

For X-band (10 GHz) , B = 1 MHz

For F_n = 4.9 dB = 3.09 (from figure 2.3)

Assume:

A probability of detection of 0.9, and a false alarm rate of 1 in 15 minutes (one pulse above the signal threshold in (15)(60)(100000) cycles). Using these numbers to enter Fig. 2.4, the signal-to-noise ratio, $(S_o/N_o)_{min}$ can read from this figure

$(S_o/N_o)_{min} = 14.7$ dB = 29.51
$kT_o = 4\times10^{-21}$ W/Hz

From eq. 2.16

$S_{min} = 3.65\times10^{-13}$ watts.

C. MAXIMUM RADAR RANGE

From eq. 2.11

$$P_r = \frac{P_t (A_e)^2 \sigma n^{3/4}}{4\pi R^4 \lambda^2 Ls} \qquad (2.17)$$

For the minimum detectable signal, S_{min}, the range is R_{max}. Solving eq. 2.11 for R_{max} gives

$$R_{max} = \left[\frac{P_t (A_e)^2 \sigma n^{3/4}}{4\pi \lambda^2 Ls S_{min}}\right]^{1/4} \qquad (2.18)$$

This final equation will be used throughout the calculation for radar range in this paper. Finally, table 1 and table 2 contain the nomenclature for the frequency band designation. This thesis will use the frequency from both tables to consider the radar horizon system.

TABLE 1

Standard Radar-frequency Letter-band Nomenclature

Band designation	Nominal frequency range	Specific radiolocation (radar) bands based on ITU assignments for region 2
HF	3-30 MHz	
VHF	30-300 MHz	138-144 MHz
		216-225
UHF	300-1000 MHz	420-450 MHz
		890-942
L	1000-2000 MHz	1215-1400 MHz
S	2000-4000 MHz	2300-2500 MHz
		2700-3700
C	4000-8000 MHz	5250-5925 MHz
X	8000-12,000 MHz	8500-10,680 MHz
K_u	12-18 GHz	13.4-14 GHz
		15.7-17.7
K	18-27 GHz	24.05-24.25 GHz
K_a	27-40 GHz	33.4-36 GHz
mm	40-300 GHz	

TABLE 2

The US has led in Introducing Unilaterally a New System Covering a Wider Range

Band	Approx frequency	Approx wavelength
HF	10-30 MHz	30-10 m
VHF	30-100 MHz	10-3 m
A	100-300 MHz	3-1 m
B	300-500 MHz	100-60 cm
C	0.5-1 GHz	60-30 cm
D	1-2 GHz	30-15 cm
E	2-3 GHz	15-10 cm
F	3-4 GHz	10-7.5 cm
G	4-6 GHz	7.5-5 cm
H	6-8 GHz	5-3.75 cm
I	8-10 GHz	3.75-3 cm
J	10-29 GHz	30-15 mm
K	20-40 GHz	15-7.5 mm
L	40-60 GHz	7.5 -5 mm
M	60-100 GHz	5-3 mm

1. Radar Horizon

Radar signal is an electromagnetic wave and travels in straight lines. This implies that a target can only be detected if is in line-of-sight. That is, it will not be visible if it is below the horizon. The distance from a radar at height h_1 to the horizon may be determined by simple geometry. The radius of the earth is approximately 3450 nmi. The radar earth's radius is 4/3X3450 = 4600 nmi, (assuming a factor of 4/3 due to refraction). With this earth, the distance to the radar horizon is

$$d = 1.23\sqrt{h_1} \qquad (2.19)$$

where

d is in nautical miles

h_1 is in feet

The distance computed from eq. 2.19 is approximately 16 percent more than the true distance, or optical, horizon [Ref. 4]. If the target is at a height h_2, the maximum range at which it can be detected is

$$R_{max_h} = 1.23(\sqrt{h_1} + \sqrt{h_2}) \qquad (2.20)$$

<u>**Example**</u>:

Given:

d = horizon distance

h_1 = radar height above sea level = 16.4 ft (5 m)

R_{max_h} = 24.84 nmi (46 km)

From eq. 2.19;

d = 4.98 nmi (9225 m)

From eq. 2.20;

h_2 = 260.62 ft (79.44 m)

Figure 2.5 shows a plot of the maximum radar horizon range, R_{max_h}, versus the target height above sea level, h_2, for a given radar height, h_1. It also shows the maximum range of the radar, R_{max}, based upon the strength of the echo. The intercept zone of the missile is indicated in the figure based upon the given minimum and maximum target range and altitude.

In Fig. 2.5;

m_1, m_1' is the missile minimum range and altitude

m_2, m_2' is the missile maximum range and altitude

h_1 is the tracking radar height above sea level

h_2 is the minimum target height above sea level

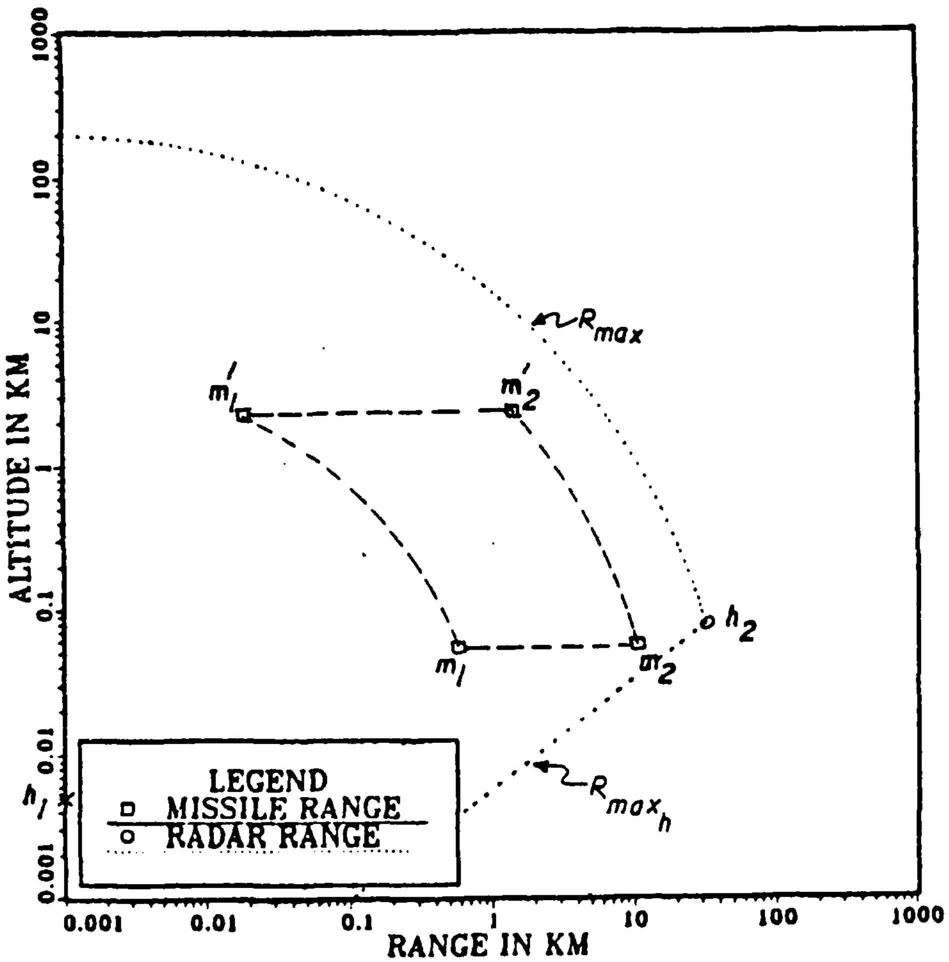

Figure 2.5 The Maximum Radar Range and the Maximum and Minimum Missile Range vs Target Altitude.

D. TYPES OF MISSILE GUIDANCE

Missile guidance may be divided into 4 types. [Ref. 5]

1. Command Guidance

Command guided missiles are missiles whose guidance instructions or commands come from sources outside the missile. Fig. 2.6 illustrates one example of a command guidance system. In this type of guidance, a tracking system that is separated from the missile is used to track both the missile and the target. The tracking system may consist of two separate tracking units, one for the missile and one for the aircraft, or it may consist of one tracking unit that tracks both vehicles. The tracking can be accomplished using radar, optical, laser, or infrared system. A radar beacon or infrared flare on the tail of the missile can be used to provide information to the tracking system on the location of the missile. The target and missile ranges, elevations, and bearings are continuously fed to a computer. Using the position and position rate information, the computer determines the flight path the missile should be take that will result in a collision with the aircraft. It compares this computed flight path with the predicted flight path of the missile based on current tracking information and determines the correction signals required to move the missile control surfaces to change the current flight path to the new one. These signals are the command guidance and are sent to the missile receiver via either the missile tracking system, or a separate command link, such as a radio, or it can be sent along a wire between the launching platform and the missile.

Besides steering instructions, the command link may be required to transfer other instructions to the missile, such as fuze arming, receiver gain setting, and warhead detonation. The specific path along which the missile is

navigated is determined by the type of guidance law used by the system. A particular type of command guidance and navigation where the missile is command to always lie on the line-of-sight between the aircraft tracking unit and the aircraft is known as command to line-of-sight (CLOS) or 3-point guidance. This particular type of guidance is sometimes mistakenly called beam-rider guidance. Command guidance is used mostly with short range missile systems because of the relatively large tracking errors that occur at long range.

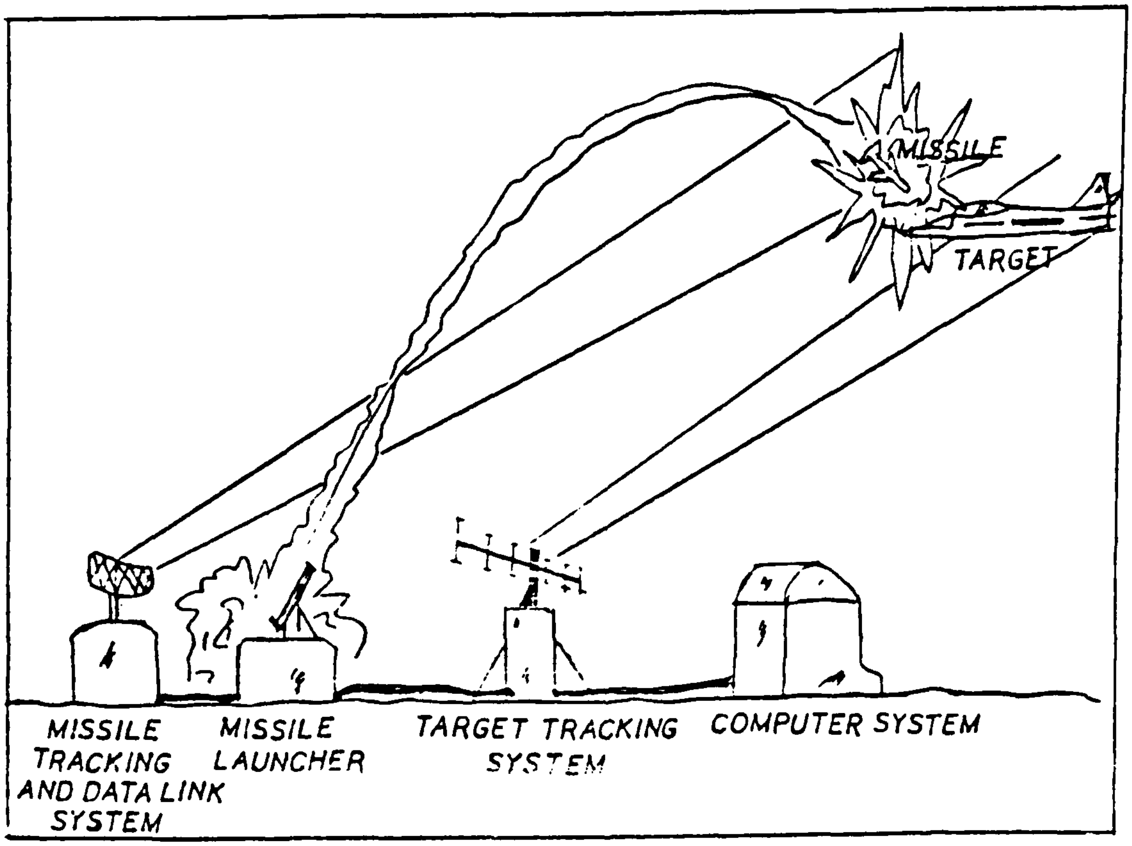

Figure 2.6 A Type Command Guidance System.

2. Beam-Rider Guidance

In the beam-rider type of guidance, illustrated in Fig. 2.7, the aircraft is tracked by an electromagnetic beam transmitted by a tracking system off-board of the missile.

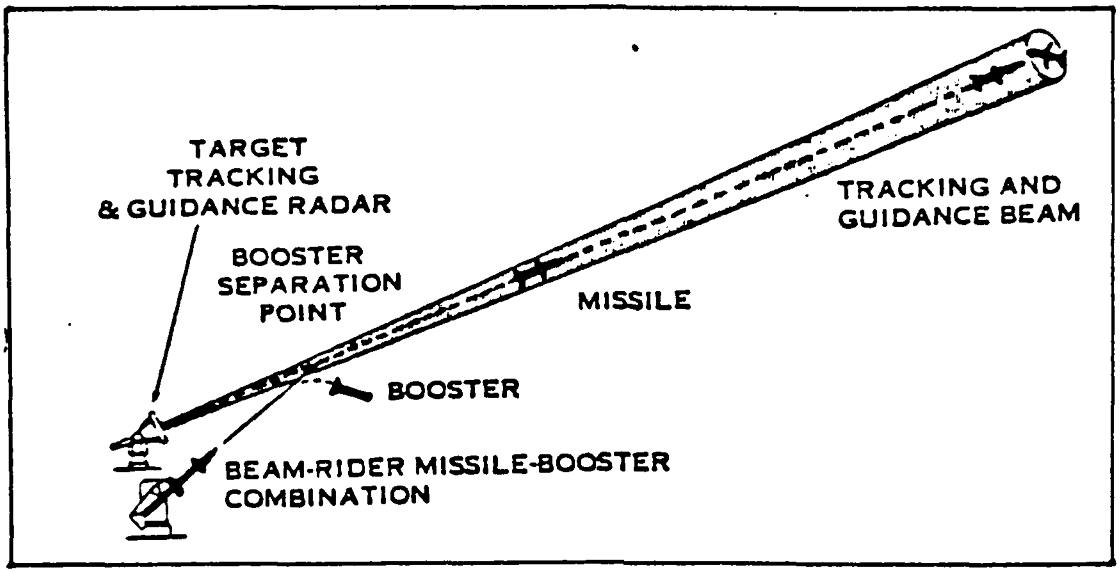

Figure 2.7 A Single Beam Beam-Rider Missile System.

The guidance equipment on-board the missile includes a rear-ward facing antenna that senses the target tracking beam. Steering signals that are based on the position of the missile with respect to the center (or the scanning axis) of the target tracking beam are computed on-board and sent to the control surfaces. These correction signals produce control surface movements intended to keep the missile as nearly as possible in the center of the target tracking beam. The missile can thus be said to ride the beam; it is not see the target. There is manually a wider, lower power beam used to capture the missile shortly after it's launched. The beam the missile rides can either track the

aircraft directly, or a computer can be used to predict the direction the missile beam should be pointing to effect an eventual collision of the missile with the aircraft. In this situation, a separate tracker is required to track the target, as shown in Fig. 2.8

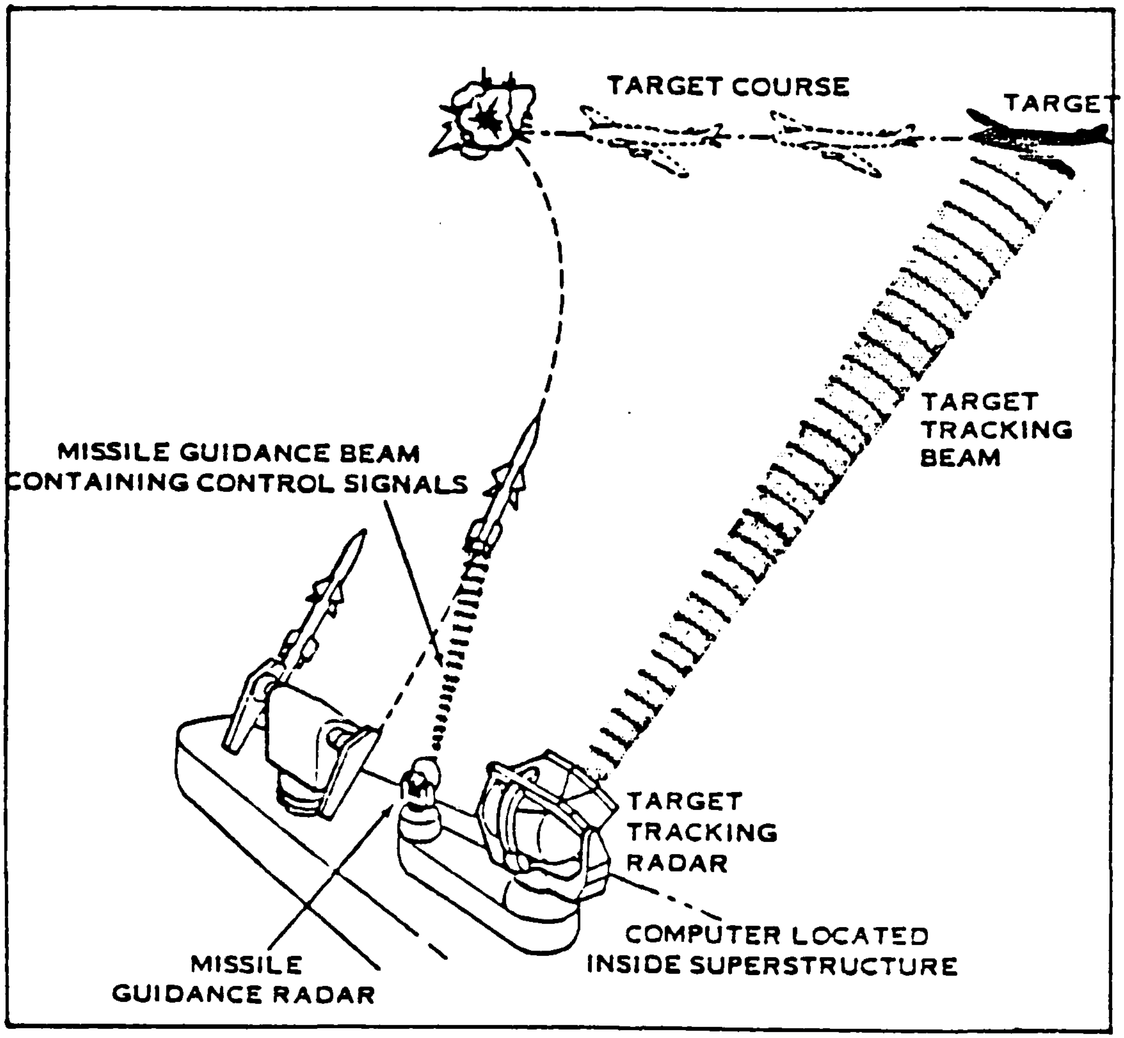

Figure 2.8 A Dual Beam Beam-Rider Missile System.

The beam-rider missile guidance system has both advantages and disadvantages. It permits the launching of

large number of missile into the same control or target tracking beam, since all of the guidance equipment is carried in the missile. This, however, makes each missile relatively large and expensive. Furthermore, the tracking beam must be reasonably narrow to insure an intercept, and the chance of loss of the missile through target maneuvering and evasion is increased. The problem of large tracking error for long range targets usually restricts beam-rider missile to short range.

3. <u>Homing Guidance</u>

The expression homing guidance is used to describe a missile guidance system that can determine the position of the aircraft and can formulate its own commands to guide itself to the aircraft. With homing guidance, the tracking error is usually reduced as the missile approaches the aircraft. There are three major types of homing systems: active, semi-active, and passive.

a. Active

If the aircraft is tracked by electronic radiation equipment in the missile, the system is referred to as active.

An example is a system that uses a radar transmitter located on the missile to illuminate the aircraft, and then uses the radar reflections from the aircraft for guidance. A major advantage of active homing is the fact that the missile can be launched and forgotten by the operational unit. No further tracking is required. This is referred to as fire-and-forget or launch-and-leave. Disadvantages of active homing are the additional weight and expense for each missile and the fact that the radiation from the missile can reveal its presence.

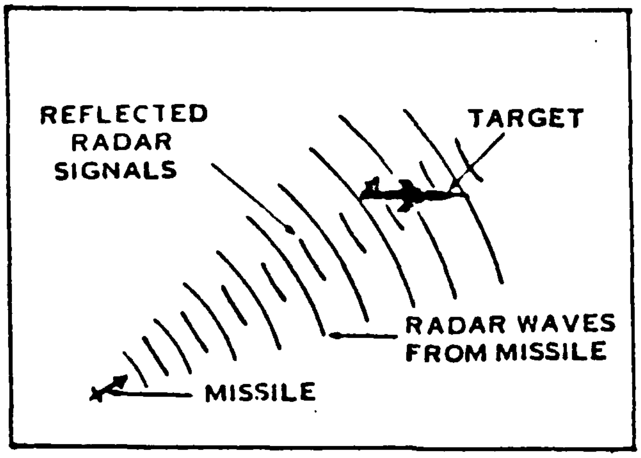

Figure 2.9 Active Homing.

b. Semi-active

If the aircraft is illuminated by a tracking beam from some source not on the missile, and if the beam reflections from the aircraft in the direction of the missile are used by the missile for guidance, the system is referred to as a semi-active homing (SAH) system. The missile may also require direct illumination from the illuminator on to a rearward facing receiver to use in the processing of the reflected signal from the target.

With this type of guidance, the aircraft may know it's being tracked, but it does not know if a missile is on the way. A SAH missile may or may not require continual target illumination. This type of guidance has progressed from a requirement for continuous illuminator per target to a system with a single illuminator that can track and illuminate several targets on a time-share basis. Thus, the missile receives the reflected illumination periodically. This is referred to as sample-data SAH.

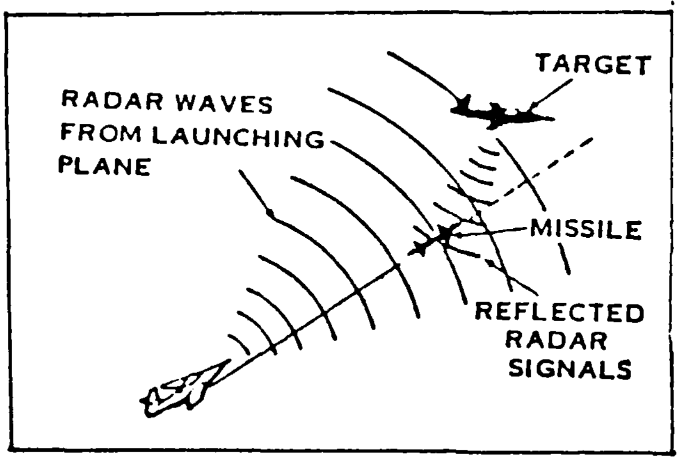

Figure 2.10 Semi-active Homing.

c. Passive

Passive homing systems use electromagnetic emissions or natural reflections from the aircraft itself for guidance. One example is an infrared homing guidance system which homes in (closes) on the heat generated by the aircraft. Another is the anti-radiation missile that homes in on radar navigation or fire control signals or on jamming signals from electronic countermeasure equipment in the aircraft.

4. Retransmission Guidance

This type of guidance, also known as track-via-missile (TVM), is the latest technique to be used to direct missiles toward air targets. An illustration of TVM is given in Fig. 2.12. Typically, a radar tracking system tracks both the target and the missile, as in command guidance. However, in TVM the target tracking beam also serves as a target illuminator, and a receiver on the missile detects the reflected illumination, as in semi-active homing guidance.

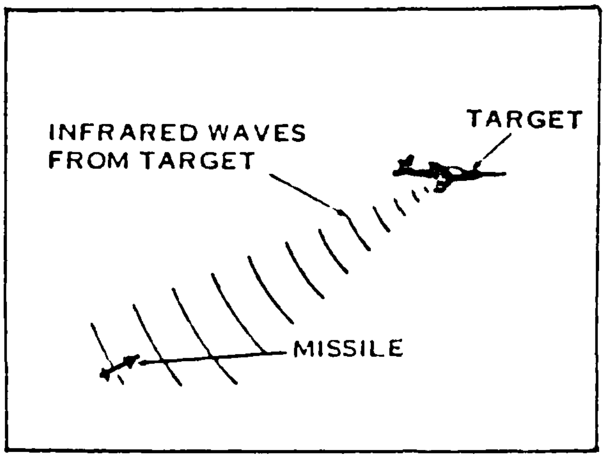

Figure 2.11   Passive Homing.

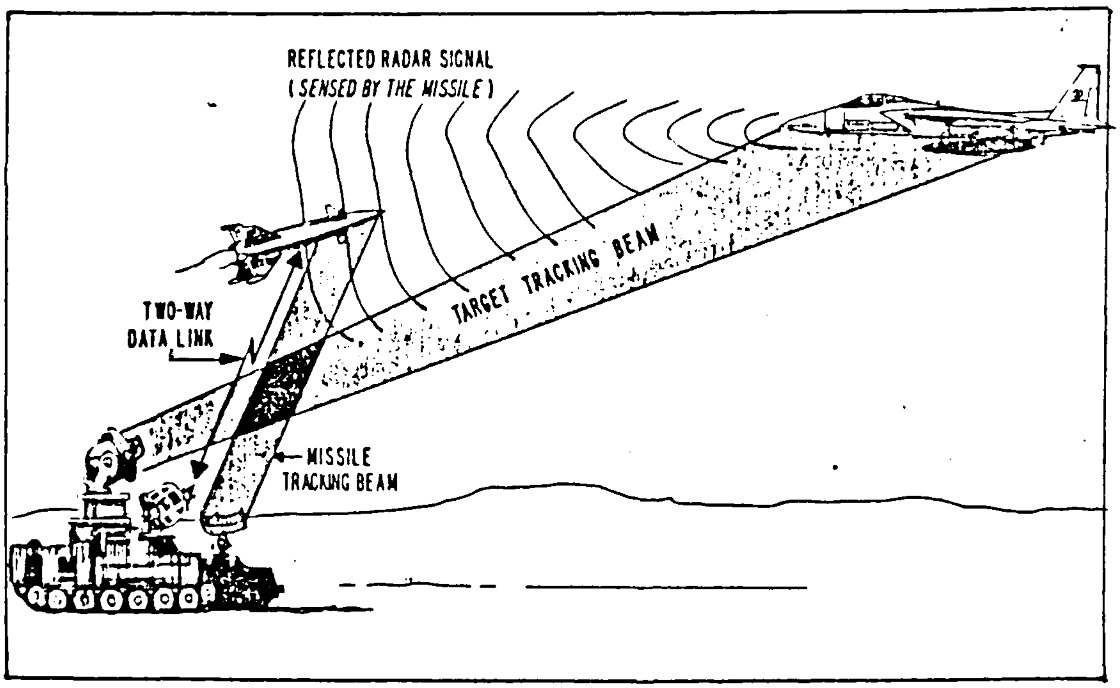

Figure 2.12   A Retransmission (TVM) Guidance System.

The information on the relative target angular position gathered by the missile is relayed to a control unit.

The missile is of tandem, two-stage design with a cylindrical body and ogival nose. The booster is of a larger diameter than the main body and has cruciform fins indexed in line with the missile tail control surfaces which in turn lie immediately to the rear of the missile wings. Guidance is provided either by a beam-riding system or a semi-active radar homing. The missile is launched from an electrically-operated, remotely-controlled, twin (dual) arm Mk 10 launcher.

1. Physical Description

Dimensions. [Ref. 14]

Length:

RIM-2A 14 ft 10 in (4.52 m)
24 ft 1 in (8.25 m) with booster

RIM-2F 14 ft 9 in (4.5 m)
26 ft 2 in (7.98 m) with booster

Span:

RIM-2A 46 in (1.17 m)

RIM-2F 42 in (1.07 m)

Diameter: 13.5 in (34.3 cm)

Systems.

Launchers: [Ref. 7], [Ref. 14]

A twin (dual) arm launcher.

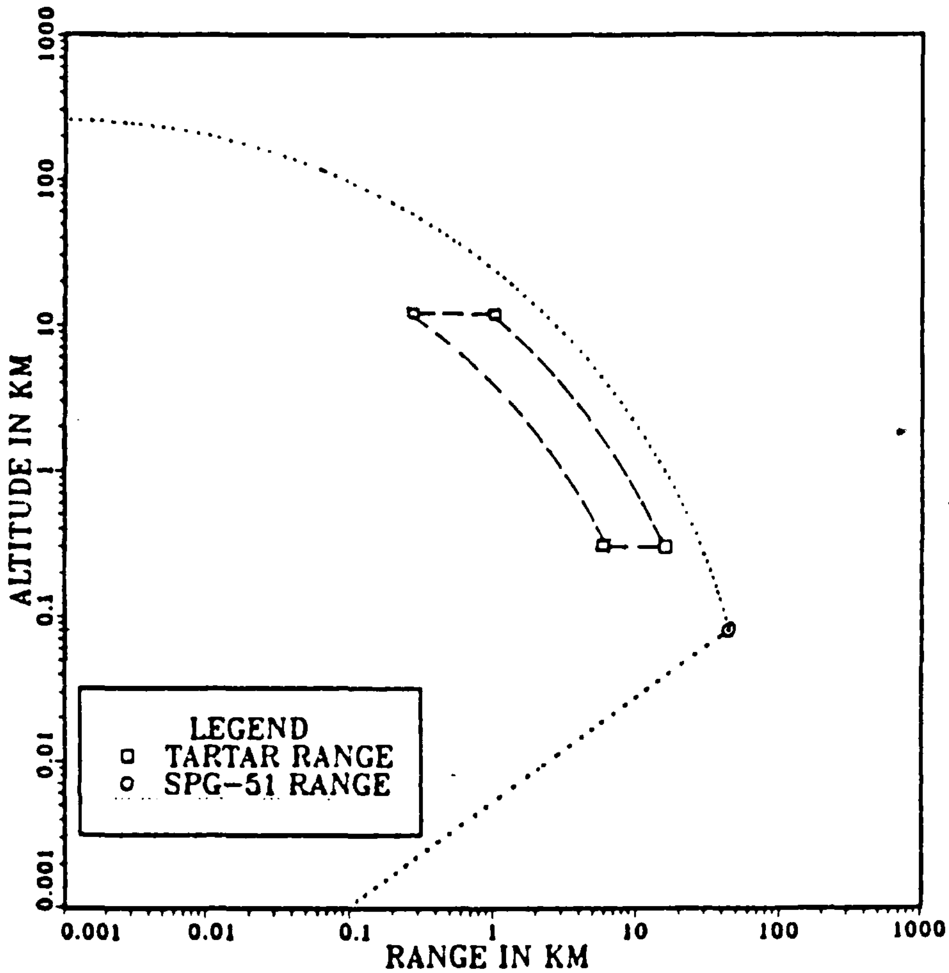

Figure 3.1 Comparison of Tartar Missile and SPG-51 Tracking Radar.

B. TERRIER (RIM-2S)

Terrier has the classification, RIM-2A, RIM-2E, RIM-2F, and RIM-2D (nuclear warhead). Terrier is no longer in production but is still in service. It is gradually being replaced by SM1-ER and SM2. Current systems are visually distinguishable from the early versions by the change of wing planform from the original cropped-delta shape to the current strake-like outline.

Minimum/Maximum Range: [Ref. 8: p. 275], [Ref. 17: p. 52]

min. 16,000 - max. 40,000 m

Minimum/Maximum Altitude: [Ref. 17: p. 52]

984 - 40,000 ft (300 - 12,000 m)

Target Maneuverability:

no information available

Target Destructibility: [Ref. 8]

Single Shot Kill Probability, Pkss = 0.85

Tartar vs SPG-51

Tracking in C-band (6 GHz), $\lambda = 0.05$ m
Antenna diameter, d = 2.44 m
Antenna area, A = 4.67 sq.m

Assume:

Receiver bandwidth, B = 1 MHz
Noise figure, F = 4.6 dB = 2.88 (from fig. 2.3)
$(S_o/N_o)_{min}$ = 14.7 dB = 29.51
From equation 2.16; $S_{min} = 3.4 \times 10^{-13}$ watts

Assume:

For an antenna efficiency, $\rho = 0.85$, $A_e = 3.97$ sq.m
For target cross section 1 sq.m, n = 30, and Ls = 20
Average power = 5 KW

From equation 2.18; $R_{max} = 46$ km

Fig. 3.1 shows the maximum radar range and the maximum and minimum missile range versus target altitude.

Explosive Type: [Ref. 16]

High Explosive (HE) warhead with H-6 main charge

4. Target Detection, Tracking, and Missile Guidance

Tartar is a medium range, supersonic, surface-to-air, shipborne guided missile system. The missile utilizes semi-active radar homing guidance system and the proportional navigation law. Incoming targets are designated to the computer system by the SPS-52 3-D long range radar. The Tartar semi-active missile guidance requires target velocity (i.e. doppler) data as well as direction passed via the fire control system. The SPG-51 tracks the target using C-band pulse doppler. The missile is fired toward the target, and ultimately steers itself toward the energy reflected by the target. The target is illuminated by the SPG-51 X-band radar. The missile obtains its doppler information by comparing the target reflected beam with a beam transmitted directly by the SPG-51 radar; i.e., from frequency in X-band continuous wave. The target and missile are tracked by the SPG-51 which combines the feed system in the same 8-ft dish.

Type of Guidance: [Ref. 15]

Semi-active Radar Homing (SARH)

Type of Navigation:

Proportional Navigation

5. Performance

Speed: [Ref. 14]

Mach 2.8

Description: The SPG-51 is a C/X-band tracking and illuminating radar. It is part of the Mk 74 Gun/Missile Fire Control Systems [Ref. 13: pp. 178-179]. The antenna is a parabolic dish with an 8 ft diameter. Tracking is by C-band pulse doppler and target illumination is by X-band continuous wave. The C/X-band combined feed system allows the advantage of using a single high-gain antenna.

Launch Weight. [Ref. 14]

1,425 lb (646 kg)

2. Propulsion

Dual thrust, single solid propellant rocket motor. (1xMk 27 Mod 2, 3, Dual thrust, Dual gain rocket, PU/AP motor). [Ref. 14], [Ref. 15]

3. Warhead Section

Type of Warhead: [Ref. 16]

Fragmentation Warhead

Weight of Warhead: [Ref. 8: p. 275]

117 lb (53.2 kg) for RIM-24A
130 lb (54.5 kg) for RIM-24B

Fuze System: [Ref. 7], [Ref. 14]

Direct Action (DA) and Proximity Fuze

Damage Mechanism:

a large number of fragments

Tartar and 1 single arm Mk 13 Mod 0 launcher with a magazine capacity for 40 Tartar missiles.[5]

4. 4 Coontz Class (DDG) 1 Tartar.[6]
5. 4 Kidd Class (DDG) 2x2 Tartar missile.[7]
6. 6 Brooke Class (DD) with 1 single arm Mk 22 Mod 0 launcher with a magazine capacity for 16 Tartar missiles.[8]
7. 4 Converted Forrest Sherman Class with 1 single arm Mk 13 Mod 1 launcher with a magazine capacity for 40 Tartar missiles.

The Tartar's console:

Guided Missile Launcher Systems (GMLS) Mk 26 fire control receives command from Gun/Missile Fire Control (GMFC) Mk 74.

Types of radar required for Tartar missile:

Surveillance radar.

Type: AN/SPS-52 3-D long range radar.

Tracking radar.

Type: AN/SPG-51D tracking/illuminating radar.

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[5]Tartar missile had been replaced by the Standard SM1-MR missile.

[6]Replaced by 1 single arm Mk 13 launcher with a magazine capacity for 40 Standard SM1-MR missiles.

[7]Replaced by 1/Mk26 Mod 0, and 1/Mk26 Mod 1, launchers with a magazine capacity for 52 Standard SM 1-MR missiles.

[8]Tartar missile had been replaced by the Standard SM1-MR missile.

action (DA) and proximity fuze. The Tartar missile is no longer in production and is being replaced by the Standard SM1-MR missile.

1. Physical Description

Dimensions. [Ref. 7]

Length: 15.0 ft (4.6 m)

Diameter: 1.13 ft (343.0 mm)

Wing Span:3.5 ft (1.06 m)

Systems.

Launchers: [Ref. 8], [Ref. 9]

A twin (dual) arm launcher.

The US ships fitted with the Tartar missile are: [Ref. 10], [Ref. 11], [Ref. 12]

1. 2 California Class (CGN) with 2 single arm Mk 13 launchers with a magazine capacity for 80 Tartar missiles. (2x1 Tartar).[3]
2. 3 Virginia Class (CGN) with 2 twin (dual) arm Mk 26 launchers with a magazine capacity for 68 Tartar missiles. (2x2 Tartar).[4]
3. 23 Charles F. Adam Class (DDG) with 1 twin (dual) arm Mk 11 Mod 0 launchers with a magazine capacity for 42

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[3]Replaced by 2 single arm Mk 13 Mod 3 launchers with a magazine capacity for 80 Standard SM1-MR missiles. [Ref. 12: p. 624]

[4]Replaced by 2/Mk26 twin (dual) arm launchers (1/Mod 1 fwd, 1/Mod 0 aft) with a magazine capacity for 68 Standard SM1-MR missiles.

III. UNITED STATES NAVY

The surface-to-air missiles in the US Navy are:

1. TARTAR Missile.[1]
2. TERRIER (RIM-2s) Missile.[2]
3. STANDARD SM1-MR (RIM-66B) Missile.
4. STANDARD SM1-ER (RIM-67A) Missile.
5. STANDARD SM2-MR (RIM-66C) Missile.
6. STANDARD SM2-ER (RIM-67C) Missile.
7. RAM (Rolling Airframe Missile).
8. SEA SPARROW/NATO SEA SPARROW Missile.
9. SEA CHAPARREL Missile.

A. TARTAR

The Tartar missile is a medium-range missile and is still in widespread service in NATO navies and elsewhere, providing primary air defence for ships of destroyer size and secondary defence for some large vessels. The Tartar missile utilizes a fully automatic magazine handling and loading system with an electrically-driven, remotely-commanded, twin (dual) arm Mk 11 or Mk 26 launcher. Also, it can be fired from a single arm Mk 13 or Mk 22 launcher. Guidance is by semi-active radar homing with the proportional navigation guidance system.

The Tartar missile has a cylindrical body with an ogival nose and long narrow cruciform fixed wings almost touching the wider tail control surfaces. It has a 646 kg launch weight and carries 53.2 kg fragmentation warhead with direct

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[1] Tartar missile will be replaced by the Standard SM-MR missile. [Ref. 6: p. 230]

[2] Terrier missile will be replaced by the Standard SM-ER missile. [Ref. 6: p. 228]

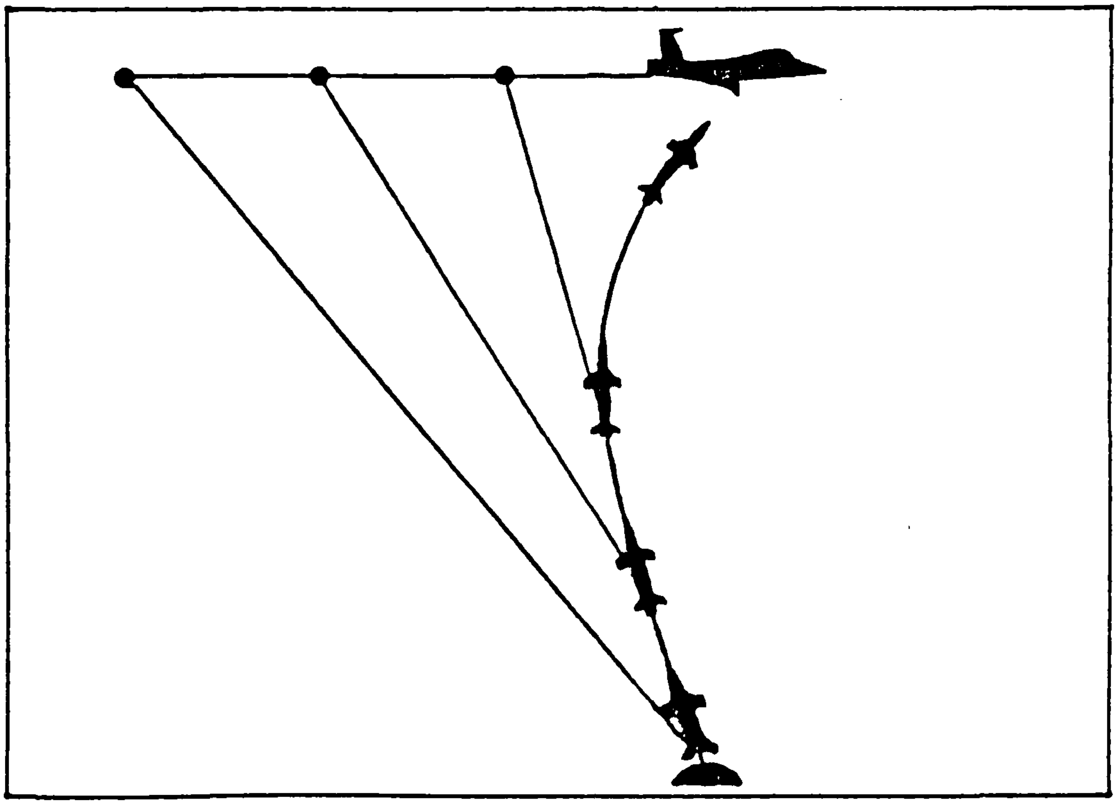

Figure 2.16 Proportional Navigation.

determine the appropriate steering commands to drive the missile back to the target tracking line. These commands are then relayed to the missile over a data link, such as a wire or radio.

4. Proportional Navigation

The most common method for changing the missile heading to cause a target intercept is proportional navigation or pro nav. In order to do proportional navigation, the guidance system must be able to determine the time rate of change of the LOS between the missile and the target, as illustrated in Fig. 2.16 This can be accomplished by equipment located on the missile or on the ground. When ground-based equipment is used, the location of both the missile and the target must be determined. In proportional navigation, the guidance system attempts to maintain an essentially constant LOS angle, and hence cause a collision, by making the rate of change of the missile heading directly proportional to the rate of change of the LOS.

3. Command to Line-of-Sight

In the CLOS, the missile is constantly being steered to lie on the line between thw target tracker and the target, as shown in Fig. 2.15; thus the alternate name 3-point guidance. This type of trajectory is typically used only in short range missile systems.

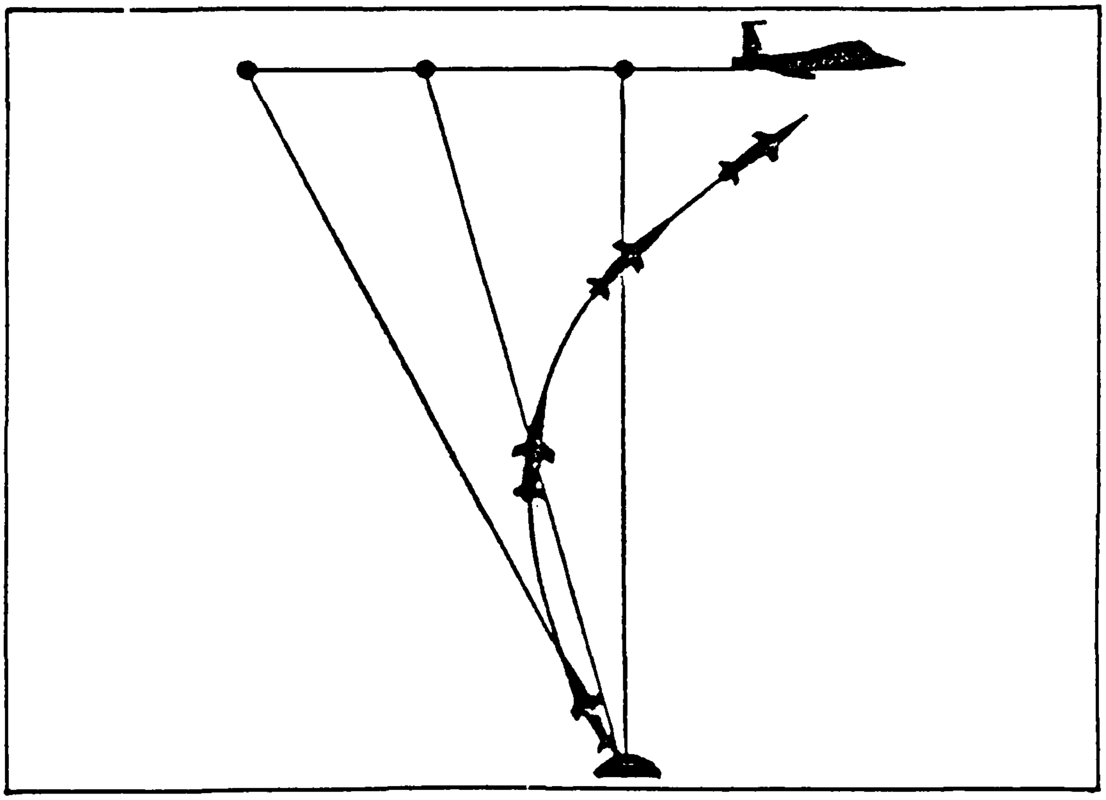

Figure 2.15 Command to Line-of-Sight.

An example of a CLOS system is one in which the target is tracked visually, using optics, and the missile is tracked by a sensor at the tracker that observes the off-axis position of flare located on the tail of the missile. The amount of offset of the missile from the LOS from the tracker to the target is used by the guidance system to

2. Lead Angle

In the lead angle or constant bearing trajectory, shown in Fig. 2.14, the guidance system flies the missile along a lead trajectory that results in an eventual intercept with the aircraft.

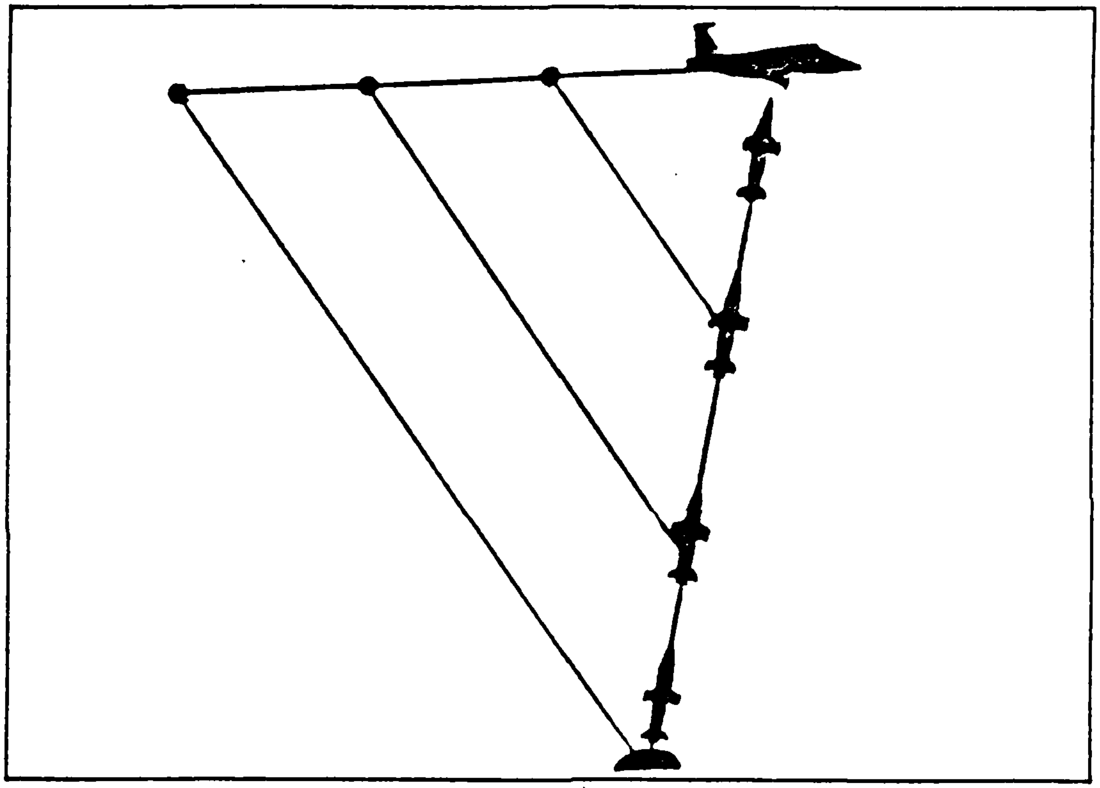

Figure 2.14 Lead Angle.

For constant-speed, non-maneuvering aircraft, the line-of-sight between the missile and the aircraft remains at a constant angle, and the missile flies a straight line trajectory. This is often referred to as a colli·ion course. If the aircraft changes direction, the new lead angle required for a collision is determined, based on an assumed straight line target flight path, and the missile is maneuvered to that new heading.

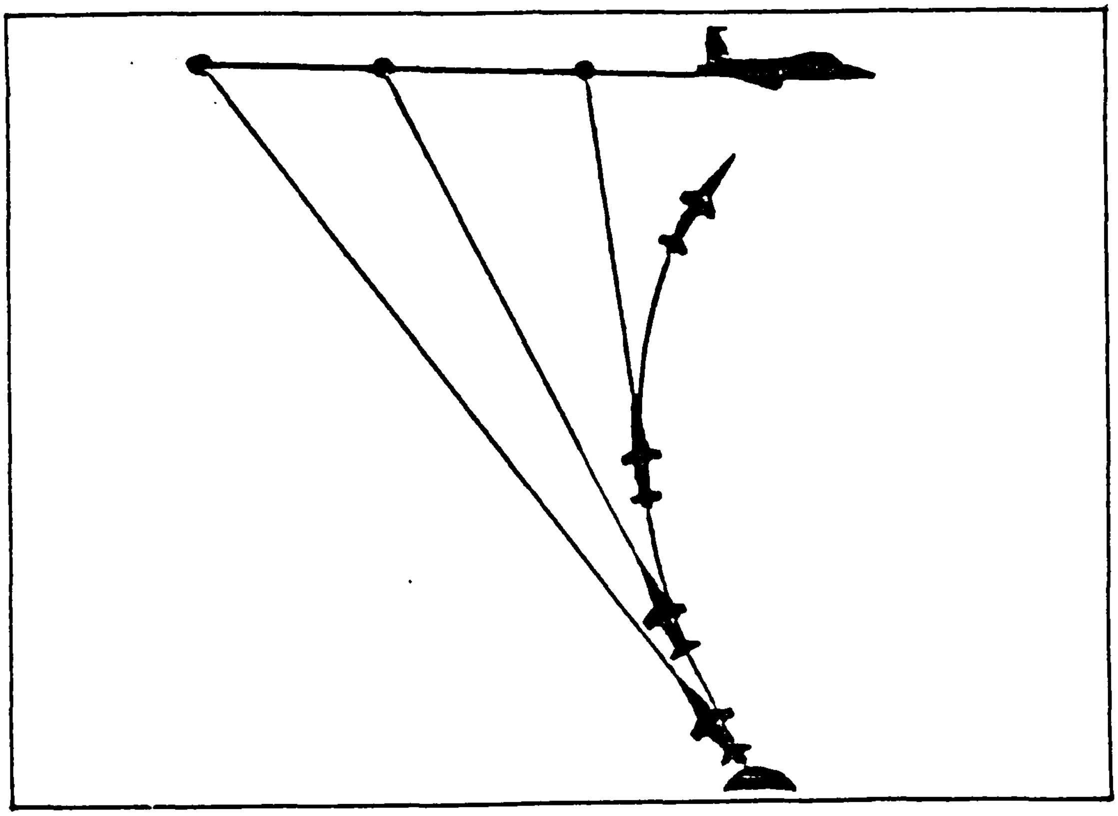

Figure 2.13 Pursuit Guidance Law.

flight. At this time, the missile must overtake the aircraft. If the aircraft attempts to evade, the last-minute angular acceleration requirements placed on the missile could exceed its aerodynamic capability, thereby causing a large miss distance. Near the end of the flight, the missile is usually coasting because the booster and sustainer motor thrusts last for only a short part of the flight. Consequently, more energy is required to make short radius, high speed turns at a time when the missile is losing speed and has the least turning capability. The most favorable application of the pursuit course is against slow moving aircraft, or for missile launched from a point directly to the rear of the aircraft, or head on an incoming aircraft.

Guidance equipment at the control unit processes the echo received from the missile and determines appropriate guidance commands, which are then sent to the missile on a data link. The tracking system usually has the capability to track several targets at one time, and the control system can direct several simultaneous engagements between missiles and aircraft.

E. GUIDANCE LAW SELECTION

The guidance law for a missile is the analytical formulation used by the guidance system to convert sensed target information into missile steering commands. Four general guidance laws are in use, and each will be discussed. [Ref. 5]

1. Pursuit Guidance
2. Lead Angle (Constant Bearing Guidance)
3. Command to Line-of-Sight
4. Proportional Navigation

1. Pursuit

In the pursuit trajectory, illustrated in Fig. 2.13, the missile flies directly toward the target at all times. Thus, the line-of-sight between the missile and the aircraft is maintained essentially along the heading of the missile by the guidance system. Missiles flying a pursuit course usually end up in a tail chase situation.

There are two basic objections to the pursuit method. First, the maneuvers required of the missile become increasingly hard during the last, and critical, stages of flight. Second, the missile speed must be considerably greater than aircraft speed. The sharpest curvature of the missile flight path usually occurs near the end of the

The US ships fitted with the Terrier missile are: [Ref. 11], [Ref. 12]

1. 4 Kitty Hawk Class with 2 twin (dual) arm Mk 10 launchers with a magazine capacity for 80 Terrier missiles.[9]
2. 1 Truxtun Class with 1 twin (dual) arm Mk 10 launcher with a magazine capacity for 60 Terrier missiles.[10]
3. 1 Bainbridge Class (CGN) with 2 twin (dual) arm Mk 10 Mod 5/6 launchers with a magazine capacity for 80 Terrier missiles.[11]
4. 1 Long Beach Class (CGN) with 2 twin (dual) arm Mk 10 Mod 1/2 launchers with a magazine capacity for 120 Terrier missiles.[12]
5. 9 Leahy Class (CG) with 2 twin (dual) arm Mk 10 Mod 5/6 launchers with a magazine capacity for 80 Terrier missiles.[13]

---

[9] In this class the USS Constellation has a Mk 10 Mod 3 launcher on the starboard quarter and a Mod 4 launcher on the port quarter. She has RIM-2D Terrier systems which will be replaced by 3 NATO Sea Sparrow launchers (Mk 29). [Ref. 12: p. 78]

[10] Replaced by 1 twin (dual) arm Mk 10 Mod 8 launcher with a magazine capacity for 60 Standard SM1-ER missiles. [Ref. 12: p. 78]

[11] Terrier missile replaced by Standard SM1-ER missile.

[12] Replaced by 2 twin (dual) arm Mk 10 Mod 1/2 launchers forward with a magazine capacity for 120 Standard SM1-ER missile.

[13] Replaced by 2 twin (dual) arm Mk 10 Mod 5/6 launchers with a magazine capacity for 80 Standard SM2-ER missiles.

6. 9 Belnap Class (CG) with 1 twin (dual) arm Mk 10 Mod 7 launcher with a magazine capacity for 60 Terrier missiles.[14]
7. 10 Coontz Class (DDG) with 1 twin (dual) arm Mk 10 Mod 0 launcher with a magazine capacity for 40 Terrier missiles.[15]

The Terrier's console:

Guided Missile Launcher Systems (GMLS) Mk 10 receives fire control command from Mk 74 Fire Control System.

Types of radar required for the Terrier missile:

Surveillance radar.

Type: SPS-43 search radar.

SPS-48 3-D height finding radar.

Tracking radar.

Type: SPG-55 guidance radar.

Description: The SPG-55 is a C-band monopulse guidance (track) radar which has a peak power of 1 MW, a pulse width for transmit of 12, 13, 0.1 microsecond and a pulse width for Compressed: 0.1, 1, 0.1 microsecond and with PRF of 427 Hz. The illuminator is operated in X-band continuous wave. A typical SPG-55 consists of a main antenna, a capture

[14]Replaced by 1 twin (dual) arm Mk 10 Mod 7 launcher with a magazine capacity for 60 Standard SM1-ER missiles.

[15]Replaced by 1 twin (dual) arm Mk 10 Mod 0 launcher with a magazine capacity for 40 Standard SM2-ER missiles.

antenna for ECCM operation, a cluster horn antenna, and a Doppler antenna. The radome has a cassegrain feed system, in which power is fed from the rear of the main reflector is reflected off a secondary reflector in front of the main reflector. The SPG-55 is also used for the semi-active type [Ref. 13]. Doppler tracking employs CW illuminator signals which are used to control the semi-active Terrier in flight. Maximum range in beam-riding mode is 60,000 ft. In beam-riding operation, the missile is steered into a 1.6X1.6 degree main beam, which nutates about 30 Hz in synchronism with the capture beam, and when the nutation axis of the guidance beam coincides with that of the track beam it is locked onto the target. In semi-active operation, the 2 X-band beams, which have an average power of 5 KW and a 0.8 x 0.8 degree beam, are radiated in 2 beams; one beam is used to illuminate the target for the missile seeker. The other beam illuminates the rear of the missile to establish a rear reference signal for the guidance computer in the missile.

Launch Weight.

2,900 lb (1,315 kg) for RIM-2A [Ref. 14].

3,070 lb (1,390 kg) for RIM-2D,E,F [Ref. 18: p. 219].

2. Propulsion

Tandem Integral Rocket Motor.

Launch: A solid fuel rocket booster.

Cruise: A solid fuel sustainer.

3. Warhead Section

Type of Warhead: [Ref. 8], [Ref. 16]

Controlled Fragmentation Warhead

Weight of Warhead: [Ref. 8: p. 153]

218 lb (99 kg) for RIM-2A

275 lb (125 kg) for RIM-2F

Fuze System: [Ref. 14]

Proximity fuze

Damage Mechanism:

a large number of fragments

Explosive Type: [Ref. 16]

High Explosive (HE) warhead with Comp B main charge

4. Target Detection, Tracking, and Missile Guidance

Terrier is a shipborne surface-to-air beam-riding guidance missile (RIM-2A, RIM-2D). A typical control sequence might be:

1. Incoming targets are detected at long range by the SPS-43 Air Search Radar.

2. More precise target location by the SPS-30 3-D Height-finding Radar.
3. As the target comes into range, the target is designated to the SPG-55.

The SPG-55 locks on to the target, the launcher is aimed and a missile is fired as soon as the range is correct. The SPG-55 beam continually tracks the target. The guidance equipment on-board the missile includes a rearward facing antenna that senses the target tracking beam. Steering signals that are based on the position of the missile with respect to the center of the target tracking beam are computed by on board tactical data system [Ref. 7: p. 113] and sent to the tail control surfaces. These correction signals produce control surface movements intended to keep the missile as nearly as possible in the center of the beam until the warhead detonates in the vicinity of the target.

For RIM-2E, RIM-2F, the semi-active radar homing missile, the guidance and control section of the missile tracks a target and directs and stabilizes the missile on its course to the target. The guidance system requires The guidance system requires a target signal which is transmitted by the guided missile Mk 74 fire control system and reflected from the target so that the missile's front receiver keeps on tracking the reflected continuous wave signal from the target. The missile itself compares these two signals to determine the new flight path until the end of engagement.

Type of Guidance:

Beam-riding for RIM-2A, D [Ref. 7], [Ref. 14].

Semi-active radar homing (SARH) for RIM-2E, F [Ref. 18: p. 219].

Type of Navigation:

no information available

5. Performance

Speed:

Mach 1.8 for RIM-2A [Ref. 8]

Mach 2.5 for RIM-2D, E, F [Ref. 11], [Ref. 18]

Minimum/Maximum Range:

max. 12 mi. (19.3 km) for RIM-2A [Ref. 17: p. 53].

max. 46.25 mi. (74 km) for RIM-2F [Ref. 8: p. 274].

Minimum/Maximum Altitude: [Ref. 8: p. 274]

50 - 80,000 ft (15 -24,400 m)

Target Maneuverability: [Ref. 8]

Aircraft at speeds up to 600 mph.

Target Destructibility: [Ref. 8: p. 165]

A 75 percent kill probability with 2 salvoes against a 600 kt target with a 60,000 ft range at 40,000 ft altitude.

Terrier vs SPG-55

Beam-riding mode.

Beam width = $1.6^{\circ} \times 1.6^{\circ}$

R_{max} = 18 km

Semi-active mode.

Beam width = $0.8^{\circ} \times 0.8^{\circ}$

Tracking in X-band (10 GHz), λ = 0.03 m

Average power = 5 KW

Assume:

Antenna diameter, $d = 2.44$ m

Antenna area, $A = 4.67$ sq.m

Receiver bandwidth, $B = 1$ MHz

Noise figure, $F = 4.9$ dB $= 3.09$ (from fig. 2.3)

$(S_o/N_o)_{min} = 14.7$ dB $= 29.51$

From equation 2.16; $S_{min} = 3.65 \times 10^{-13}$ watts

Assume:

For antenna efficiency, $\rho = 0.85$, $A_e = 3.97$ sq.m

For target cross section 1 sq.m, $n = 30$, and

$Ls = 20$

From equation 2.18; $R_{max} = 70$ km

Fig. 3.2 shows the maximum radar range and the maximum and minimum missile range versus target altitude.

C. STANDARD SM1-MR (RIM-66B)

This is the basic development model to replace Improved Tartar. System comprises Mk 11 twin (dual) arm launcher, Mk 13 single arm launcher, Mk 22 twin (dual) arm launcher, or Mk 26 twin (dual) arm launcher with a vertical ready-service magazine containing 40, 40, 16, or 16 missiles respectively, a computer, an air-search radar, a three-dimensional SPS-48 radar, and two SPG-51 guidance radar. [Ref. 7], [Ref. 19]

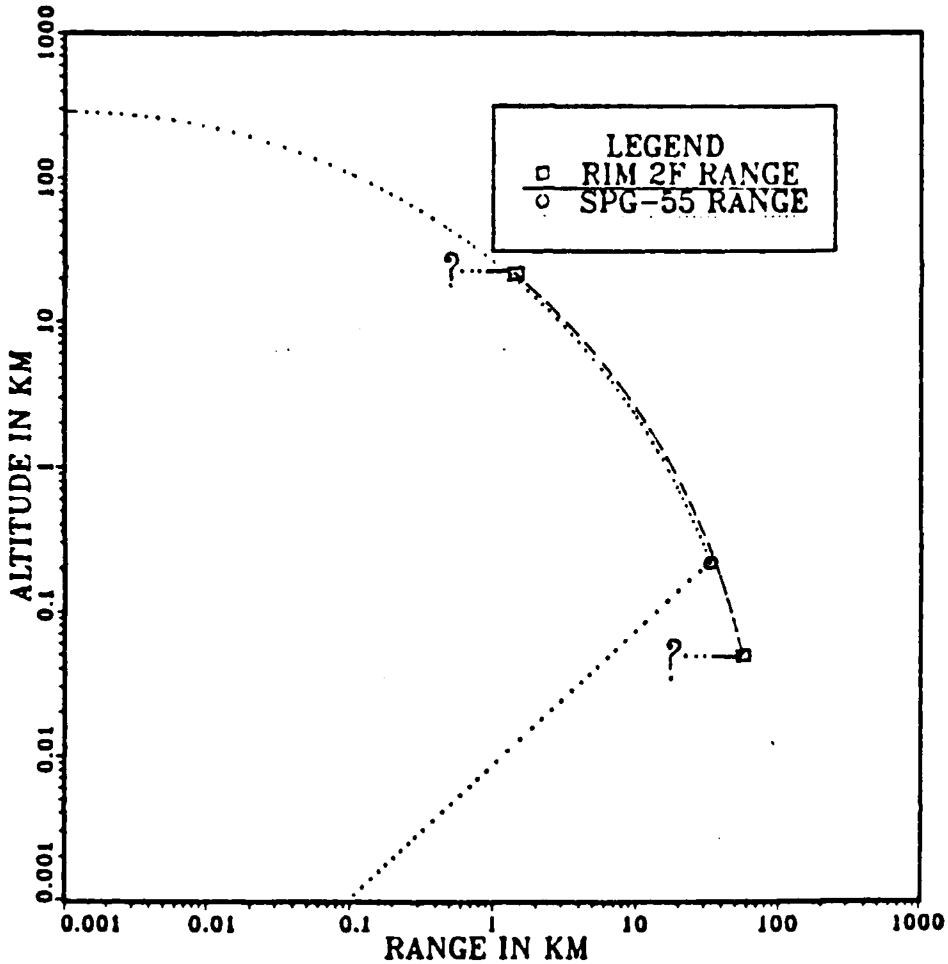

Figure 3.2 Comparison of Terrier Missile and SPG-55 Tracking Radar.

1. <u>Physical Descriptions</u>

Dimensions. [Ref. 7], [Ref. 14]

Length: 176.0 in (4.47 m)

Diameter: 13.5 in (343.0 mm)

Span: 36.0 in (914.0 mm)

Systems.

Launchers: [Ref. 19]

A twin (dual) arm launcher and a single arm launcher.

Both types of launchers are used for Standard SM1-MR missile are:

1. Mk 11 is twin (dual) arm launcher with a magazine capacity for 40 missiles.
2. Mk 13 is single launcher with a magazine capacity for 40 missiles.
3. Mk 22 is twin (dual) arm launcher with a magazine capacity for 16 missiles.
4. Mk 26 is twin (dual) arm launcher with a magazine capacity for 16 missiles.

The US ships fitted with Standard SM1-MR missiles are: [Ref. 11], [Ref. 12], [Ref. 19]

1. 4 Virginia Class (CGN) with two twin (dual) arm Mk 26 Mod 0/1 launchers with two magazine capacities for total 68 Standard SM1-ER missiles.[16]
2. 2 California Class (CGN) with two single arm Mk 13 Mod 3 launchers with two magazine capacities for total 80 Standard SM1-MR missiles.

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[16]Standard SM1-MR to be replaced by Standard SM2-MR in FY 1983 [Ref. 9: p. 623]

3. 1 Albany Class (CG) with two twin (dual) arm Mk 11 launchers with two magazine capacities for total 80 Standard SM1-MR missiles.
4. 4 Kidd Class (DDG) with one twin (dual) arm Mk 26 Mod 0 launcher with a magazine capacity for total 18 missiles and one twin (dual) arm Mk 26 Mod 1 launcher with a magazine capacities for total 34 Standard SM1-MR missiles.
5. 23 Charles F. Adams Class (DDG) with one twin (dual) arm Mk 13 launcher with a magazine capacity for total 40 Standard SM1-MR missiles and one twin (dual) arm Mk 11 Mod 0 launcher with a magazine capacity for total 42 Standard SM1-MR missiles.
6. 4 Decatur Class (DDG) with one twin (dual) arm Mk 13 launcher with a magazine capacity for total 40 Standard SM1-MR missiles.
7. 31 Perry Class (FFG) with one single Mk 11 Mod 4 launcher with a magazine capacity for 40 Standard SM1-MR missiles.
8. 6 Brooke Class (DD) with one single Mk 22 Mod 0 launcher with a magazine capacity for 16 Standard SM1-MR missiles.

The Standard SM1-MR's console: [Ref. 14], [Ref. 19]

There are 4 types of Guided Missile Launcher Systems (GMLS): Mk 11, Mk 13, Mk 22, Mk 26 which had commanded fire control from Mk 74 Fire Control System.

Types of radar required for Standard SM1-MR missile: [Ref. 19]

Surveillance.

Type: SPS-48 3-D air search radar.

Tracking radar.

Type: SPG-51 tracking/illuminating radar.

Description: See Tartar radar.

Launch Weight: [Ref. 14]

1,280 lb (581 kg)

2. Propulsion

Dual-thrust solid-propellant motor Mk 56 Mod 0. [Ref. 7], [Ref. 15]

3. Warhead Section

Type of Warhead: [Ref. 16]

Fragmentation Warhead

Weight of Warhead: [Ref. 8: p. 153]

275 lb (125 kg)

Fuze Systems: [Ref. 6: p. 230], [Ref. 7]

Proximity Fuze and contact fuze

Damage Mechanism:

a large number of fragments

Explosive Type: [Ref. 7]

High Explosive (HE) Warhead with PBXN-101 & PBXN-106 main charge

4. <u>Target Detection, Tracking, and Missile Guidance</u>.

Standard SM1-MR is medium range surface-to-air missile. The missile has a communication link for midcourse guidance and semi-active radar homing for terminal guidance phase. The incoming targets are detected by the air search long range radar SPS-48. The SPS-48 uses multiple beams to combine long range with a high data rate and multiple-pulse detection. Finally, the information about the target is transferred to the Mk 74 fire control system.

A SPG-51, with C-band pulse doppler radar, tracks the target in conjunction with X-band continuous wave method for target illumination. When the missile is launched, the target and missile ranges, elevations, and bearing are continuously fed to a computer. During the midcourse phase, illuminated by the tracking beam from SPG-51, the missile uses the command link guidance from a computer to determine the flight path for the missile and compares this computed flight path with the predicted flight path of the missile based on current tracking information and determines the correction signals required to move the missile control surfaces to change the current flight path to the new one. In the terminal phase, the missile is switched to the

semi-active homing and the target track beam serves as the target illuminator.

Type of Guidance: [Ref. 19]

Semi-active radar homing (SARH)

Type of Navigation:

no information available

5. <u>Performance</u>

Speed: [Ref. 6: p. 230]

Mach 2.5

Minimum/Maximum Range: [Ref. 14]

max. 19 mi (30.6 km)

Minimum/Maximum Altitude: [Ref. 19]

60 - 80,000 ft (18 - 24,400 m)

Target Maneuverability:

no information available

Target Destructibility:

no information available

SM1-MR vs SPG-51

Tracking in C-band (6 GHz), λ = 0.05 m

Antenna diameter, d = 2.44 m

Antenna area, A = 4.67 sq.m

Assume:

Receiver bandwidth, B = 1 MHz

Noise figure, F = 4.6 dB = 2.88 (from fig. 2.3)

$(S_o/N_o)_{min}$ = 14.7 dB = 29.51

From equation 2.16; $S_{min} = 3.4 \times 10^{-13}$ watts

Assume:

For an antenna efficiency, $\rho = 0.85$, $A_e = 3.97$ sq.m

For target cross section 1 sq.m, n = 30, and

Ls = 20

Average power = 5 KW

From equation 2.18; $R_{max} = 46$ km

Fig. 3.3 shows the maximum radar range and the maximum and minimum missile range versus target altitude.

D. STANDARD SM1-ER (RIM-67A)

The RIM-67B Standard 1 Extended Range has been out of production since 1974 and has been succeeded by the RIM-67C Standard 2 Extended Range.

1. Physical Description

Dimensions. [Ref. 14]

Length: 314.0 in (7.98 m)

Diameter: 13.5 in (343.0 mm)

Span: 36.0 in (914.0 mm)

Systems.

Launchers: [Ref. 19]

A twin (dual) arm launcher.

Mk 99, is C-band (42.4 KW, PRF 10,400-18,100) for target acquisition and tracking, and X-band CW illuminator which is slaved to the SPY-1 phased-array long-range radar. Also, the illuminator has 10 KW average power. [Ref. 14]

Launch Weight: [Ref. 15]

2,996 lb (1,359 kg)

2. Propulsion

Launch: 1/Mk 12 solid fuel booster.

Cruise: 1/Mk 30 solid fuel sustainer. [Ref. 15]

3. Warhead Section

Type of Warhead: [Ref. 16]

Fragmentation Warhead

Weight of Warhead:

no information available

Fuze System: [Ref. 6: p. 228], [Ref. 14], [Ref. 20: p. 174]

Active proximity fuze and contact fuze

Damage Mechanism:

a large number of fragments

2. 9 Leahy Class with one twin Mk 10 Mod 0 launcher with a magazine capacity for 40 Standard SM2-ER missiles.
3. 10 Coontz Class (DDG) with one twin Mk 10 Mod 0 launcher with a magazine capacity for 40 Standard SM2-ER missiles.
4. 9 Belnap Class (CG) with one twin Mk 10 Mod 7 launcher with a magazine capacity for 60 Standard SM2-ER missiles.
5. 4 Ticonderoga Class (CG) with two twin Mk 26 Mod 1 launchers with two magazine capacities for total 88 Standard SM2-ER missiles.

The Standard SM2-ER's console: [Ref. 11], [Ref. 12]

Missile Launching System Mk 10 or Mk 26 Mod 1 receives fire control command from Mk 99 Gun/Missile Fire Control System.

Types of radar required for Standard SM2-ER missile: [Ref. 14]

Surveillance radar.

Type: SPY-1 phased array radar.
AN/SPS-49 air search radar.
AN/SPS-55 surface search radar.

Tracking radar.

Type: AN/SPG-63 Dual-channel radar.

Description:The AN/SPG-63 radar, part of the FCS

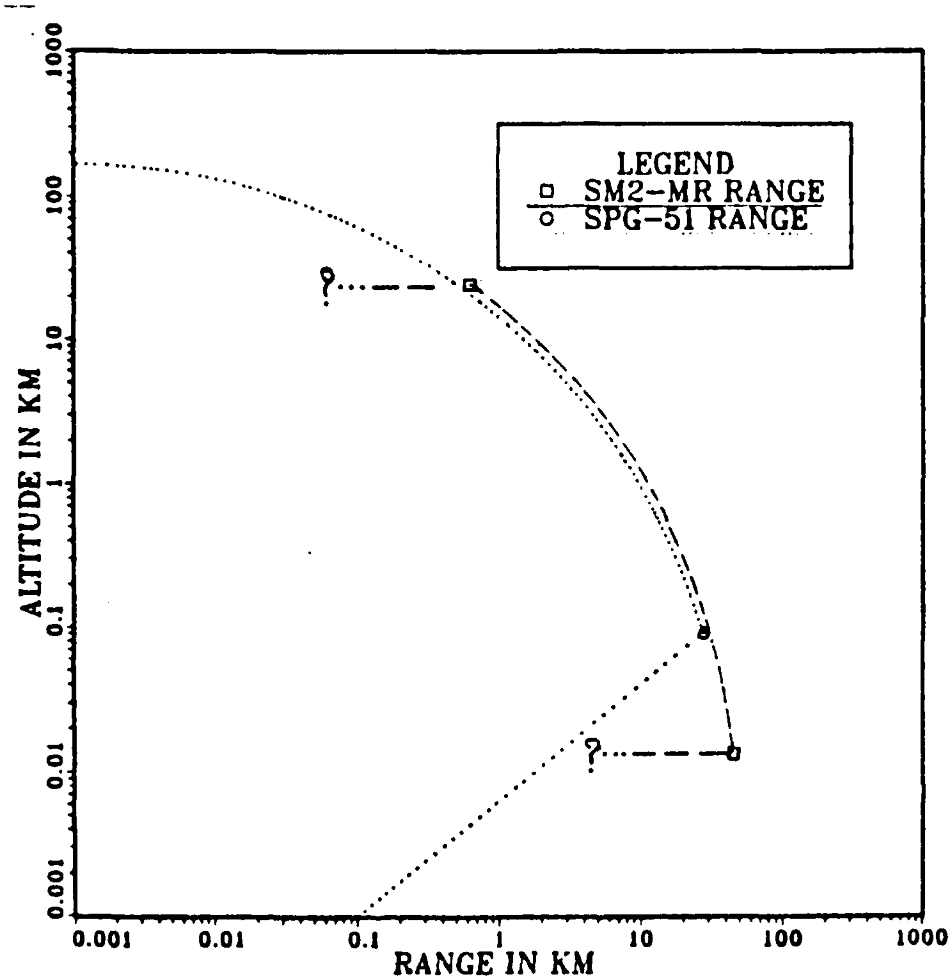

Figure 3.5 Comparison of SM2-MR Missile and SPG-51 Tracking Radar.

The US ships fitted with Standard SM2-ER missiles are: [Ref. 11], [Ref. 12], [Ref. 19]

1. 1 Long Beach Class (CGN) with one twin Mk10 Mod 0 and one twin Mk 10 Mod 1 launchers with two magazine capacities for total 120 Standard SM2-MR missiles.

Assume:

For an antenna efficiency, ρ = 0.85, A_e = 3.97 sq.m

For target cross section 1 sq.m, n = 30, and Ls = 20

Average power, P_f = 5 KW

From equation 2.18; R_{max} = 46 km

Fig. 3.5 shows the maximum radar range and the maximum and minimum missile range versus target altitude.

F. STANDARD SM2-ER (RIM-67B)

The Standard SM2-ER (ER stands for extended range), is the latest Standard SM model, and it may have a nuclear warhead option. This system is used in the Aegis missile cruisers. The missile is a long range, surface-to-air, shipborne guided missile.

1. Physical Description

Dimensions. [Ref. 14]

Length: 314.0 in (7.98 m)

Diameter: 13.5 in (343.0 mm)

Span: 36.0 in (914.0 mm)

Systems.

Launchers: [Ref. 19]

A twin (dual) arm launcher.

Type of Guidance: [Ref. 7], [Ref. 14], [Ref. 19]

Semi-active radar homing, with midcourse guidance capability, inertial reference, and improved ECCM.

Type of Navigation: [Ref. 7]

Inertial Navigation.

5. Performance

Speed: [Ref. 6: p. 230]

Mach 2.5

Minimum/Maximum Range: [Ref. 14]

max. 30 mi (48.3 km)

Minimum/Maximum Altitude: [Ref. 19]

150 - 60,000 ft (45 - 18,000 m)

Target Maneuverability:

no information available

Target Destructibility:

no information available

SM2-MR vs SPG-51

Tracking in C-band (6 GHz), $\lambda = 0.05$ m
Antenna diameter, $d = 2.44$ m
Antenna area, $A = 4.67$ sq.m

Assume:

Receiver bandwidth, $B = 1$ MHz
Noise figure, $F = 4.6$ dB = 2.88 (from fig. 2.3)
$(S_o/N_o)_{min} = 14.7$ dB = 29.51
From equation 2.16; $S_{min} = 3.4 \times 10^{-13}$ watts

Damage Mechanism:

Fragments

Explosive type: [Ref. 16]

High Explosive (HE) Warhead with PBXN-101 & PBXN-106 main charge.

4. Target Detection, Tracking, and Missile Guidance

Standard SM2-MR is a medium range shipborne surface-to-air missile. The missile uses a combination of midcourse guidance and terminal semi-active radar homing guidance. The engagement event begins when target designation is provided by SPS-48 3-D search radar or by SPS-55 surface search radar. These inputs are processed by the Aegis system to determine the possibility of engaging the target and then commands are generated for the launcher. The Aegis system commands the SPG-51 tracking radar to track and lock on the target, and the Standard SM2-MR missile to fly into engagement range.

During the midcourse guidance phase, Standard SM2-MR operates as a command-guided missile by the Aegis system. The system determines the flight path for the missile and compares this computed flight path with the predicted flight path of the missile based on current tracking information, thus obtaining the signals required to move the cruciformwing to change the current flight path to the new one until the terminal guidance phase is reached.

The terminal guidance phase is semi-active radar homing (SARH) during which the missile obtains its information by a new monopulse receiver. At the design distance the fragmentation warhead will be detonated by the active proximity fuze.

Types of radar required for Standard SM2-MR missile: [Ref. 7], [Ref. 12], [Ref. 14]

Surveillance radar.

Type: SPS-48 3-D search radar.

SPS-55 surface search radar.

Tracking radar.

Type: SPG-51 Tartar/Standard SM-MR illumination/tracking radar.

Description: SPG-51 (see Tartar's radar)

Launch Weight. [Ref. 14]

1,280 lb (581 kg)

2. Propulsion

Launch: Dual-thrust integral rocket-ramjet solid propellant booster.

Cruise: Ramjet fluid-fuel Shelldyne-H, a high density, liquid hydrogen. [Ref. 9]

3. Warhead Section

Type of Warhead: [Ref. 16]

Fragmentation Warhead

Weight of Warhead:

no information available

Fuze System: [Ref. 6: p. 230], [Ref. 20: p. 174]

Active proximity fuze and contact fuze

4. A digital computer (AN/UYK-7 in Aegis Systems) instead of SM1's analogue weapon direction system.

1. Physical Description

Dimensions. [Ref. 7], [Ref. 14]

Length: 176.0 in (4.47 m)

Diameter: 13.5 in (343.0 mm)

Span: 36.0 in (914.0 mm)

Systems.

Launchers: [Ref. 7], [Ref. 9], [Ref. 14]

A twin (dual) arm launcher.

The US ships fitted with Standard SM2-MR missiles are: [Ref. 11], [Ref. 12], [Ref. 19]

1. 4 Kidd Class (DDG) with one twin Mk 26 Mod 0 and 1 twin Mk 26 Mod 1 launchers with two magazine capacities for total 68 Standard SM2-MR missiles.
2. 4 Virginia Class (CGN) with two twin Mk 26 (1/Mod 1 fwd., 1/Mod 0 aft.) launchers with two magazine capacities for total 68 Standard SM2-MR missiles.

The Standard SM2-MR missile's console: [Ref. 11], [Ref. 12]

Missile launching systems Mk 26 receives fire control commands from Mk 74 Mod 9 Missile Fire Control System.

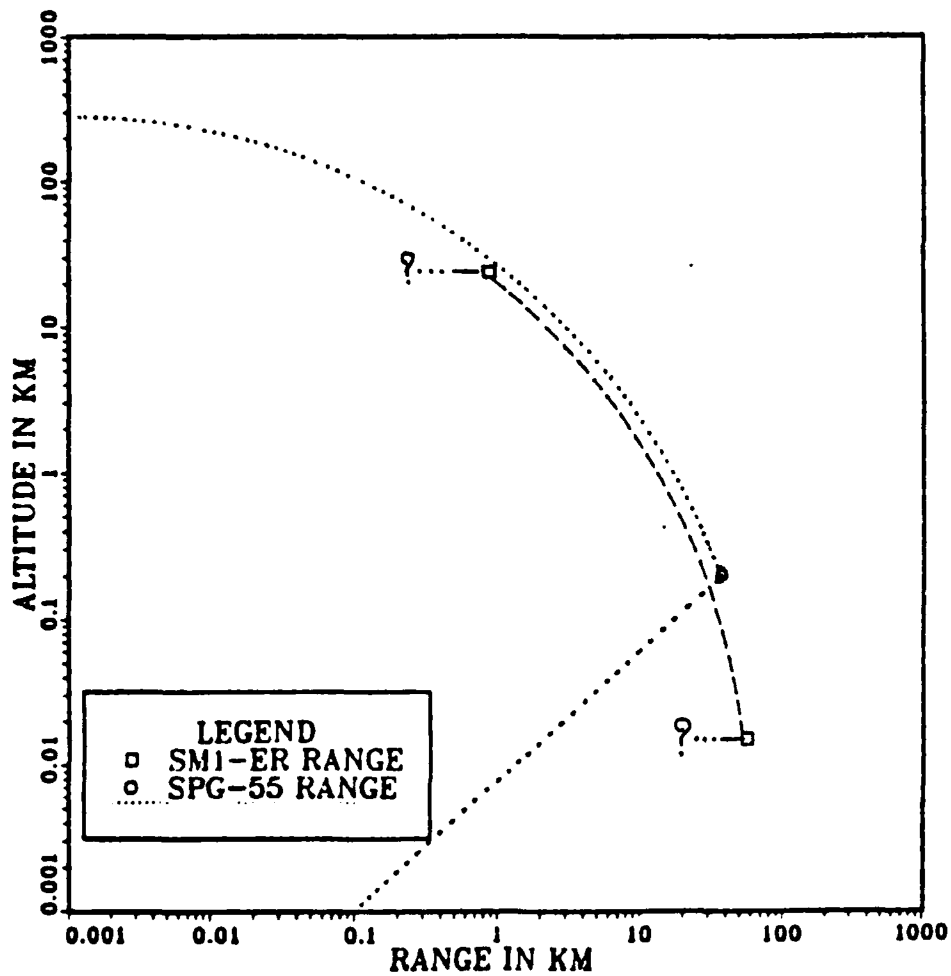

Figure 3.4 Comparison of SM1-ER Missile and SPG-55 Tracking Radar.

2. The provision of an inertial reference unit for midcourse guidance implying self-navigation by the missile to the vicinity of the target, during a midcourse phase.
3. A communication link for midcourse guidance correction and target position data updating and missile position reporting (two-way link for midcourse guidance).

SM1-ER vs SPG-55

Beam width = $0.8^{\circ} \times 0.8^{\circ}$

Tracking in X-band (10 GHz), $\lambda = 0.03$ m

Average power = 5 KW

Assume:

Antenna diameter, d = 2.44 m

Antenna area, A = 4.67 sq.m

Receiver bandwidth, B = 1 MHz

Noise figure, F = 4.9 dB = 3.09 (from fig. 2.3)

$(S_o/N_o)_{min}$ = 14.7 dB = 29.51

From equation 2.16; $S_{min} = 3.65 \times 10^{-13}$ watts

Assume:

For antenna efficiency, ρ = 0.85, A_e = 3.97 sq.m

For target cross section 1 sq.m, n = 30, and

Ls = 20

From equation 2.18; R_{max} = 70 km

Fig. 3.4 shows the maximum radar range and the maximum and minimum missile range versus target altitude.

E. STANDARD SM2-MR (RIM-66C)

The SM-2 version of the Standard-MR is intended for use aboard Aegis missile cruisers. Initially, sea tests of the SM2-MR were conducted in 1976-1977 aboard the NORTON SOUND (AVM1) [Ref. 14: p. 341].

The most important changes embodied in the SM2 are:

1. The replacement of the SM1 conical-scan SARH receiver by a monopulse receiver, including a new semi-active terminal guidance receiver with greater resistance to ECM.

incoming targets are directed to the Mk 76 missile fire control system by the SPS-48A or SPS-48C fitted on each ship. The missile guidance requires target velocity (i.e. doppler) data as well as direction transferred to the fire control system. The SPG-55B or C tracks the target and illuminates the missile.

During the flight, the missile obtains its doppler information by comparing the reflected signal from the target with a beam transmitted directly by the SPG-55 tracking/illuminating radar.

Type of Guidance: [Ref. 15], [Ref. 19]

Semi-active Radar Homing (SARH)

Type of Navigation:

no information available

5. Performance

Speed: [Ref. 6: p. 228]

Mach 2.5

Minimum/Maximum Range: [Ref. 19]

Max. 35 mi (56.3 km)

Minimum/Maximum Altitude: [Ref. 8]

50 - 80,000 ft (15 - 24,000 m)

Target Maneuverability:

no information available

Target Destructibility:

no information available

Launch Weight: [Ref. 15]

2,963 lb (1,344 kg)

2. Propulsion

Launch: 1/Mk 12 booster. [Ref. 15]

Cruise: 1/Mk 30 Mod 2 sustainer.

3. Warhead Section

Type of Warhead: [Ref. 16]

Fragmentation Warhead

Weight of Warhead:

no information available

Fuze Systems: [Ref. 6: p. 228], [Ref. 7], [Ref. 14]

Proximity Fuze and contact fuze

Damage Mechanism:

a large number of fragments

Explosive type: [Ref. 16]

High Explosive (HE) Warhead with PBXN-101 & PBXN-106 main charge.

4. Target Detection, Tracking, and Missile Guidance.

Standard SM1-ER is a medium range, supersonic, surface-to-air shipborne guide missile. The missile uses semi-active radar homing (SARH) guidance and replaces the Terrier guided missile. The operation begins when the

2. 1 Bainbridge Class (CGN) with two twin (dual) arm Mk 10 Mod 5/6 launchers with two magazine capacities for total 80 Standard SM1-ER missiles.[18]
3. 1 Long Beach Class (CGN) with two twin (dual) arm Mk 10 Mod 0/1 launchers with two magazine capacities for total 120 Standard SM1-ER missiles.[19]
4. 4 Kidd Class (DDG) with two twin (dual) arm Mk 10 Mod 0/1 launchers with two magazine capacities for total 68 SM1-ER missiles.

The Standard SM1-ER's console: [Ref. 8], [Ref. 14]

Guided Missile Launcher Systems (GMLS) Mk 10 receives fire control command from Mk 76 Mod 6 Missile Fire Control.

Types of radar required for Standard SM1-ER missile: [Ref. 19]

Surveillance radar.

Type: SPS-48 air search radar.

Tracking radar.

Type: SPG-55 tracking/illuminating radar.

Description: See Terrier's radar.

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[18]Standard SM1-ER will be replaced by Standard SM2-ER missiles.

[19]Standard SM1-ER will be replaced by Standard SM2-ER missiles.

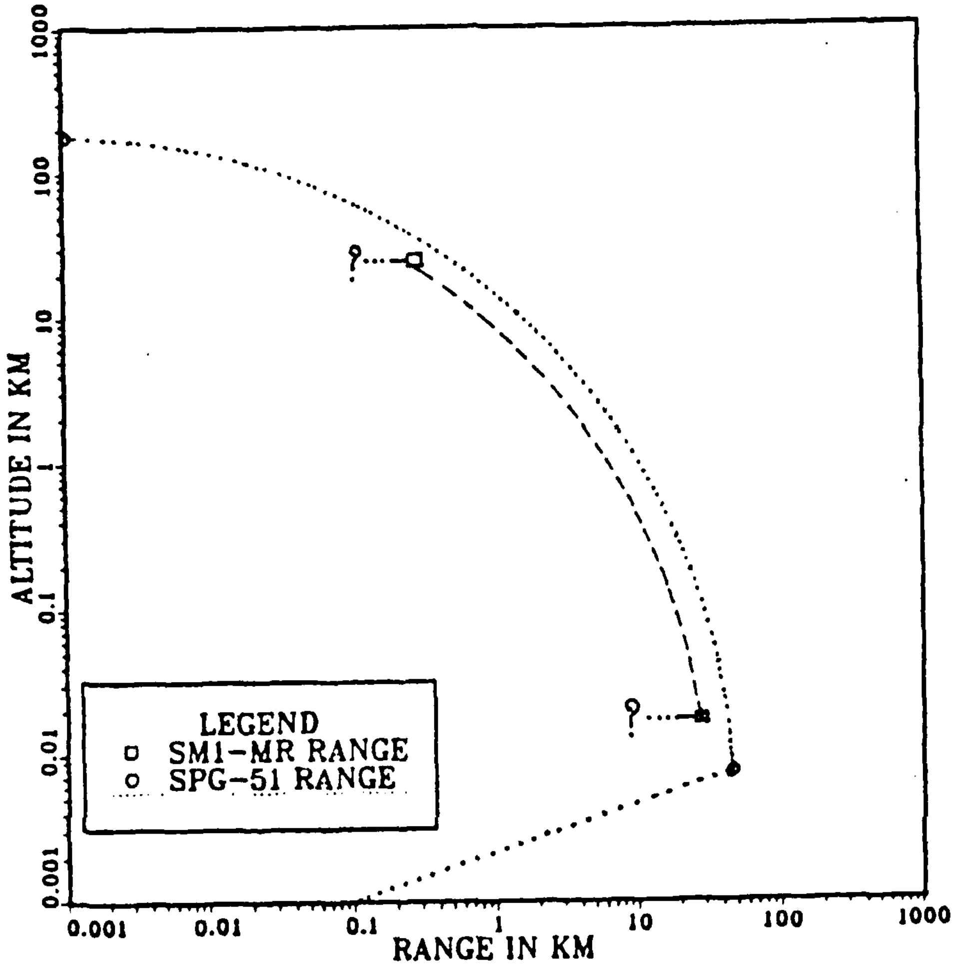

Figure 3.3 Comparison of SM1-MR Missile and SPG-51 Tracking Radar.

The US ships fitted the Standard SM1-ER missile are: [Ref. 11], [Ref. 12], [Ref. 19]

1. 1 Truxtun Class (CGN) with one twin (dual) arm Mk 10 Mod 8 launcher with a magazine capacity for 60 Standard SM1-ER missiles.[17]

---

[17]Standard SM1-ER will be replaced by Standard SM2-ER missiles.

Explosive Type: [Ref. 16]

High Explosive (HE) warhead with PBXN - 101 &
PBXN - 106 main charge.

4. Target Detection, Tracking, and Missile Guidance

Standard SM2-ER is (an extension) an improved version of the SM2-MR supersonic missile system [Ref. 7], [Ref. 14]. The missile employs a combination of command and semi-active homing guidance which depends on the Aegis system. The Standard SM2-ER has a command midcourse guidance capability, a self-contained navigation capability provided by an inertial reference unit, and a new terminal homing receiver for semi-active radar homing only during the terminal guidance phase. The operation of the system begins when the incoming targets are designated by the multi-function phased array radar, the SPY-1; these inputs are processed to determine the capability of engaging the target and then commands are generated for the Mk 26 launcher and prelaunch orders for the missile, commands for the Mk 99 fire control system for target illumination, commands to the multi-function radar, if midcourse guidance is required, and reports to the Mk 1 command and decision system. The AN/SPY-1 detects the targets automatically and commands Standard SM2-ER missile to fly into engagement zone.

The specific path along which the missile is navigated is determined by the inertial navigation law. During the missile flight, the information about the target and missile range, elevation, and bearing are continuously fed to the Mk 1 command and decision system. During the mid-course guidance phase, commands to the missile from the Mk 1 weapons control system determines the flight path for the missile.

Terminal homing is by semi-active illumination provided by slaved illuminators (SPG-63). The missile obtains its doppler information by comparing the target reflected beam with a beam transmitted directly by the SPG-63 illuminator radar, which is used for automatic target range rate tracking and, consequently, missile homing to the target. The fragmentation warhead is detonated by a centrally located explosive charge. Detonation which occurs at a small miss distance is triggered by a safety-arming device actuated in the guidance and control section.

Type of Guidance: [Ref. 15], [Ref. 19]

Semi-active radar homing, with midcourse guidance capability, inertial reference, and improved ECCM.

Type of Navigation: [Ref. 19]

Inertial Navigation.

5. <u>Performance</u>

Speed: [Ref. 6: p. 228]

Mach 2.5

Minimum/Maximum Range: [Ref. 14], [Ref. 19]

max. 75 mi (121 km)

Minimum/Maximum Altitude: [Ref. 6: p. 228], [Ref. 17: p. 50]

max. 80,000 ft (24,000 m)

Target Maneuverability:

no information available

Target Destructibility:

no information available

SM2-ER vs SPG-63

Average power, P_t = 42.5 KW

Assume:

Tracking in C-band (6 GHz), λ = 0.05 m

Antenna diameter, d = 2.44 m

Antenna area, A = 4.67 sq.m

Receiver bandwidth, B = 1 MHz

Noise figure, F = 4.6 dB = 2.88 (from fig. 2.3)

$(S_o/N_o)_{min}$ = 14.7 dB = 29.51

From equation 2.16; $S_{min} = 3.40 \times 10^{-13}$ watts

Assume:

For an antenna efficiency, ρ = 0.85, A_e = 3.97 sq.m

For target cross section 1 sq.m, n = 30, and Ls = 20

From equation 2.18; R_{max} = 80 km

Fig. 3.6 shows the maximum radar range and the maximum and minimum missile range versus target altitude.

G. ROLLING AIRFRAME MISSILE (RAM)

The Rolling Airframe Missile (RAM) or RIM-116A was developed to provide a rapid-reaction, short-range missile for shipboard defense using off-the-self components. RAM was formally called the Antiship Missile Defense (ASMD) weapon or the Antiship Cruise Missile (ASCM). The missile uses the rocket motor, warhead, and fuze from the AIM-9L Sidewider

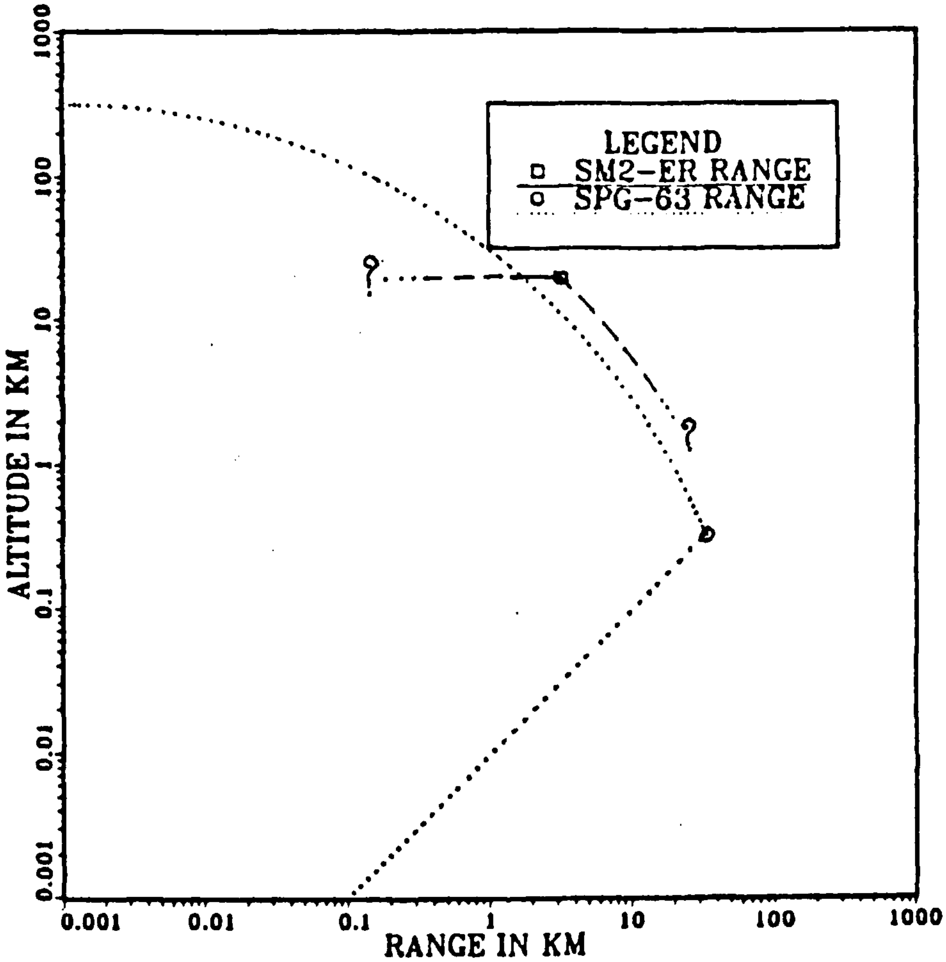

Figure 3.6 Comparison of SM2-ER Missile and SPG-63 Tracking Radar.

air-to-air missile version [Ref. 21: p. 1440]. So far, RAM does not arm any ship yet. Proposed launchers include the Sea Sparrow launcher, RAM ODALT which has ten RAMs filling in two of the eight Sea Sparrow tubes and the RAM EX-31 launcher which can fire 24 missiles. RAM itself uses a two antenna radar interferometer for initial passive RF guidance, and a passive infra-red seeker for the terminal phase. RAM needs only a single guidance channel, since the

same command, at one instant in the roll, causes the missile to pitch and at another instant with the two fins vertical, it causes the missile to turn.[20] Similarly, two rather than four interferometer antenna are required. However, the missile RF passive seeker is very broad-band, and it is informed by the ship fire control system of the frequency of the target radar at time of firing.

1. Physical Description

Dimensions. [Ref. 11] [Ref. 22],

Length: 110.0 in (2.79 m)

Diameter: 5.0 in (127.0 mm)

Span: 24.0 in (610.0 mm)

Systems.

Launchers: [Ref. 22]

A single launcher.

The RAM missile's console: [Ref. 22]

RAM EX-31 with 24 missiles per launcher.
RAM ODALT for RAM missile firing from the NATO Sea Sparrow surface missile launcher.

Types of radar required for RAM missile:

By using ship's tracking radar. So far, no specification is available. Presumably uses the same radar systems as Sea Sparrow, the Target Acquisition System (TAS) Mk23.

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[20]Limit load factor in any plane is believed to be some 25-g.

Launch Weight: [Ref. 22]

159 lb (72 kg)

2. Propulsion

Launch and cruise by 1/Mk 36 Mod 7 solid propellant rocket [Ref. 15].

3. Warhead Section

Type of Warhead: [Ref. 5]

Fragmentation Warhead with smooth casing and roof-shaped inserts or profiled charge.

Weight of Warhead: [Ref. 23: p. 175]

24.97 lb (11.35 kg)

Fuze system: [Ref. 7], [Ref. 14], [Ref. 23: p. 174]

Active optical proximity fuze

Damage Mechanism:

a large number of fragments

Explosive Type: [Ref. 16]

High Explosive (HE) Warhead with PBXN-102 & HBX-1 main charge.

4. Target Detection, Tracking, and Missile Guidance

The RAM (Rolling Airframe Missile) is in the class of the Antiship Cruise Missile (ASCM). The ASCM RAM missile consists of a 5 inch rolling airframe with dual mode passive radio frequency midcourse and IR seeker terminal homing or

passive radio frequency (RF) all the way. This guidance technique is target dependent in that it requires both active radar and IR signals from the target to function. The system operation begins when the TAS radar or ship's tracking radar tracks the incoming targets. At the same time, the ship's ESM confirms that the target is radiating and identifies the waveband. Thereafter, direction, range, elevation and RF data are passed onto the RAM control control circuits.

In the normal mode the weapon can be operated as semi-automatic system in which the operator confirms the designation of the target and fires the missile, or as a fully automatic system in which missiles are launched without the operator's intervention. When TAS Mk 23 is designed to react automatically to an incoming antiship cruise missile, designate them to RAM EX-31 or RAM ODALT illuminator (Mk 91 or Mk 115), engage them, and launch the missile. Also, it can be used in manual mode in which target information comes from outside the system.

As target information is passed to the RAM EX-31 or RAM ODALT launcher, a few seconds before firing, the first missiles are made ready, with their RF seeker gyros spun up and their IR detectors cooled down. As the missiles are fired, more missiles are prepared until the engagement is over. The system is basically programmed for one missile to be fired against each target but this program can be altered at the request of customers.

The missile's RF system is active as soon as it leaves the launcher tube. The pencil-shaped housing on either side of the nose contain forward-looking and aft-looking antenna, the latter track the ship's own radar to provide data to help the seeker to maintain its lock on the target's emissions. In the normal mode, the RF system points the IR seeker at the target and the missile's control logic

switches over from RF to IR as soon as the IR signal is sufficiently strong. The 11.35 kg warhead is designed to detonate close enough to the target to cause massive structural damage, which, at RAM's engagement range (max. 3.2 km), will prevent the incoming missile's warhead from reaching the ship.

Type of Guidance: [Ref. 22]

Dual mode which

1. Passive RF acquisition and midcourse guidance. Transition to IR for high terminal accuracy.
2. Passive RF all the way.

Type of Navigation: [Ref. 22]

Proportional Navigation

5. <u>Performance</u>

Speed: [Ref. 10] [Ref. 14],

Mach 2.5

Minimum/Maximum Range: [Ref. 10] [Ref. 14],

2 mi (3.2 km)

Minimum/Maximum Altitude:

Presumably 3 - over 100 m

Target Maneuverability:

Presumably at least 2-g

Target Destructibility:

Single Shot Kill Probability, Pkss = 0.70

H. SEA SPARROW/NATO SEA SPARROW

The Sea Sparrow and NATO Sea Sparrow are the RIM-7M [Ref. 15], which resemble closely the Sparrow AIM-7E missile in use as an air launched weapon by the Air Force of many nations. As a surface launched missile, it functions as a short-range interceptor for hostile missiles or aircraft. It is supersonic, boost-glide, semi- active homing missile, and weighs approximately 500 lb. The missile contains several innovations for operational surface-to-air missile systems. The current 8 cells NSSMS (NATO Sea Sparrow Surface Missile System) trainable launcher has up to 30 missile canisters that can be mounted in-deck.

Vertical launch SLMS (Sea Sparrow Launch System) is designed to provide point defense against antiship missiles and aircraft for the 1980s and also to allow missile engagement for surface targets. Since the missile canisters can be mounted collectively or individually in-deck, on the sides of the superstructure, or above deck, the system can be fitted on ships as small as 150 tons.

Vertical launch gives rapid reaction time, a 360 degree free fire zone and enables fast sequential engagement of high-velocity targets, the sole limitation being the number of X-band CW target tracker/illuminators (director) mounted on board. The vertical-launch technique requires the missile to be fitted with a jet van control (JVC) system in the exhaust to turn it over on to an intercept course after launch. The vertical launch canister is mounted above a longitudinal exhaust control duct, with a single plenum efflux which can be oriented in any direction. This system reduces the weight, deck area, and power requirement dramatically from those of NSSMS. This new technique is fitted with the folding wing RIM-7M Sparrow missile. Furthermore, the RIM-7M replaces the RIM RIM-7H in its upgraded Sea

Sparrow systems for the 1980s [Ref. 24: p. 73]. Primary reasons for the choice of the 7Ms are its greatly improved look-down capabilities through clutter against antiship missiles and its fuze which is optimized for low-flying targets.

1. Physical Description

Dimensions. [Ref. 14], [Ref. 19]

Length: 144.0 in (3.66 m)

Diameter: 8.0 in (203.0 mm)

Span: 40.0 in (1.02 m)

Systems.

Launchers: [Ref. 7], [Ref. 14]

A 8-tube launcher/vertical launcher.

The US ships fitted with Sea Sparrow/NATO Sea Sparrow missiles are: [Ref. 11], [Ref. 12], [Ref. 19]

1. 2 Nimitz Class with three 8-tube Sea Sparrow Mk 25 launchers and another 2 Nimitz Class with three 8-tube NATO Sea Sparrow Mk 29 launchers.
2. 1 Enterprise Type with three 8-tube NATO Sea Sparrow Mk 29 launchers.
3. 4 Kitty Hawk Class with two 8-tube NATO Sea Sparrow Mk 29 launchers.
4. 4 Forrestal Class with three 8-tube NATO Sea Sparrow Mk 29 launchers.
5. 2 Midway Class (CV) with two 8-tube Sea Sparrow Mk 25 launchers.

6. 31 Spruane Class (DD) with one 8-tube NATO Sea Sparrow Mk 29 launcher.
7. 45 Knox Class (FF) with one 8-tube Sea Sparrow Mk 25 launcher and another 1 Knox Class with one 8-tube NATO Sea Sparrow Mk 29 launcher.
8. 2 Blue Ridge Class (LCC) with two 8-tube Sea Sparrow Mk 25 launchers.
9. 5 Tarawa Class (LHA) with two 8-tube Sea Sparrow Mk 25 launchers.
10. 7 Iwo Jima Class (LPH) with two 8-tube Sea Sparrow Mk 25 launchers.

The Sea Sparrow/NATO Sea Sparrow's console: [Ref. 11], [Ref. 12]

Missile Launching Systems Mk 25 for Sea Sparrow and Mk 29 for NATO Sea Sparrow receives fire control command from Mk 91 and Mk 115 Missile Fire Control System, respectively.

Types of radar required for Sea Sparrow/NATO Sea Sparrow missile: [Ref. 14]

Surveillance radar.

Type: Target Acquisition System (TAS) Mk 23.

Tracking radar.

Type: Mk 115 Missile Systems Fire Control radar for Sea Sparrow.

Mk 91 Missile Systems Fire Control radar for NATO Sea Sparrow.

Description: Mk 115 operates in X-band CW only,

requires two antennas; a parabolic dish for transmission and a flat plate planar array for reception. Tracking errors detected by comparison of transmitted and received signals are displayed in a gun-sight atop the modified director pedestal. Manual pointing was adopted for targets with high closing velocities but relatively little angular motion relative to the ship being attacked. Interception range is over 4 nmi (7.4 km). Mk 91 operates in X-band CW with separate receiving and transmitting antenna side by side.

Launch Weight. [Ref. 15]

500 lb (227 kg)

2. Propulsion

Launch and cruise by 1/Mk 56 Mod 2 solid propellant rocket motor.

3. Warhead Section

Type of Warhead: [Ref. 5]

Continuous Rod Warhead

Weight of Warhead: [Ref. 12: p. 338]

90 lb (41 kg)

Fuze System: [Ref. 14]

Proximity Fuze

Damage Mechanism:

The rods. Approximate initial velocity of the rods is 1,000 to 1,400 m/sec [Ref. 24: p. 164].

Explosive Type: [Ref. 25]

High Explosive (HE) Warhead

4. Target Detection, Tracking, and Missile Guidance

The Sea Sparrow and NATO Sea Sparrow are short range missiles. The incoming antiship cruise missile is detected by the L-band pulse doppler Target Acquisition System (TAS) Mk 23 radar. The TAS radar is designed for short range operation in severe clutter and jamming. One of four operating modes is the normal mode, with instrument range of over 20 nmi. Once a target has been detected, the IFF system determines whether it is friendly, and the associated AN/UYK-20 computer determines whether it is to be attacked and when it can be engaged, then, it designates the target to a Sea Sparrow illuminator (Mk 91 or Mk 115). When the target tracking begins, trained and elevation orders in synchronism with the manual control Mk 51 director/illuminator is fed to the launcher. Consequently, prelaunch data and firing commands are relayed to the 8 missiles housed in individual launcher cells. The missile is fired directly at the target but above the director-target line of sight.

The guidance and control section of the missile tracks a target, directs and stabilizes the missile on its course to the target, and finally initiates the warhead detonation at the proper point of intercept. The guidance system obtains a signal by using the missile's front antenna to track the reflected continuous wave radar signal from the target. Prior to launch, the missile's rear reference

ntenna receives radar energy from a feed horn in its espective launcher cell, which tunes the missile to the irection frequency illuminating the target. During flight, hanges in lead angle are used by the missile's guidance ystem, and the missile's course is updated to maintain a arget intercept. Missile to target closing speed is erived from a doppler shift between the signals received by he front antenna and the rear reference antenna.

The continuous rod warhead expands by the detonation f a centrally located explosive charge. Detonation is triggered by a safety-arming device actuated by a firing pulse rom a fractional doppler gate in the guidance and control section, a contact fuze, or a side receiving system in the uidance and control section.

Type of Guidance: [Ref. 15], [Ref. 25]

CW semi-active radar homing.

Type of Navigation: [Ref. 25]

Lead Angle.

5. <u>Performance</u>

Speed: [Ref. 18: p. 219]

Mach 2.5

Minimum/Maximum Range: [Ref. 15], [Ref. 26: p. 311]

22,000 - 25,000 m

Minimum/Maximum Altitude: [Ref. 17: p. 47]

16 - 16,000 ft (5- 5,000 m)

Target Maneuverability:

no information available

AD-A154 243 A STUDY OF THE WORLD'S NAVAL SURFACE-TO-AIR MISSILE DEFENSE SYSTEMS(U) NAVAL POSTGRADUATE SCHOOL MONTEREY CA S SARAPARUNG DEC 84 2/3

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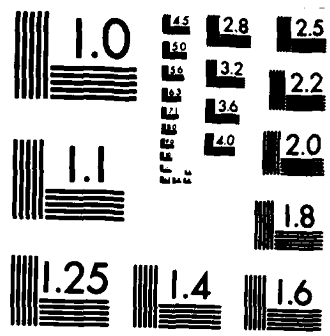

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Target Destructibility:

no information available

Sea Sparrow vs Mk 91, Mk 115

Tracking in X-band (10 GHz), $\lambda = 0.03$ m

Assume:

Antenna diameter, d = 1 m.

Antenna area, A = 0.79 sq.m

Receiver bandwidth, B = 1 MHz

Noise figure, F = 4.9 dB = 3.09 (from fig. 2.3)

$(S_o/N_o)_{min}$ = 14.7 dB = 29.51

From equation 2.16; $S_{min} = 3.65 \times 10^{-13}$ watts

Assume:

For antenna efficiency = 0.85, A_e = 0.67 sq.m

For a target cross section 1 sq.m, n = 30, and Ls = 20

Average power, P_t = 5 KW

From equation 2.18; R_{max} = 24 km

Fig. 3.7 shows the maximum radar range and the maximum and minimum missile range versus target altitude

I. SEA CHAPARREL

The Sea Chaparrel missile is a point-defence missile that uses a slightly modified launcher capable of being directed by either a gunner or a remote control of the parent vessel's fire control system [Ref. 17]. The Sea Chaparrel missile uses Mk 68 Fire Control System (FCS) [Ref. 8]. In all other aspects, it is similar to the standard land-based Chaparrel weapon [Ref. 17]. Typically, the

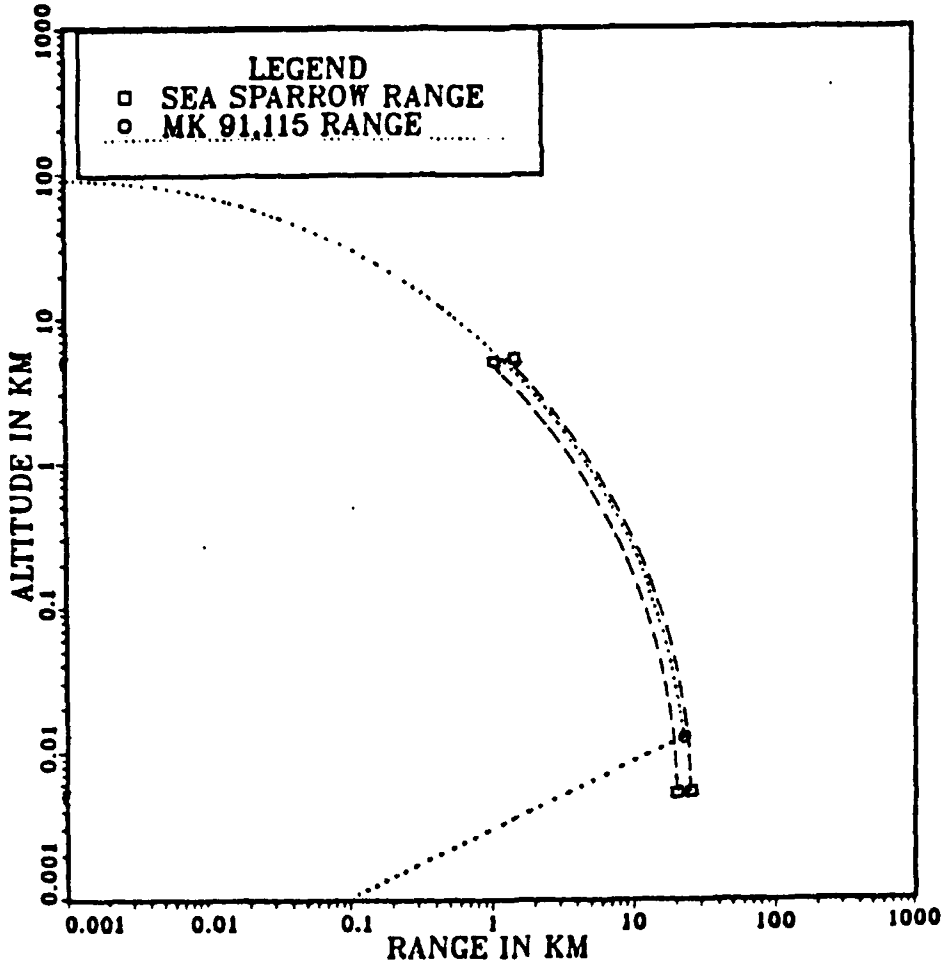

Figure 3.7 Comparison of Sea Sparrow Missile and Mk 91 & Mk 115 Fire Control Radar.

Sea Chaparrel has the same characteristics as the AIM-9D [Ref. 24: p. 37].

1. Physical Description

Dimensions. [Ref. 14: p. 226], [Ref. 24: p. 40]

Length: 113.0 in (2.87 m)

Diameter: 5.0 in (127.0 mm)

Span: 24.8 in (630.0 mm)

Systems.

Launchers:

A single arm launcher.

The US ships fitted with Sea Chaparrel missile are: [Ref. 8: p. 161]

1. Lawence
2. Hoel DDG-13
3. Coontz DLG-9

The Sea Chaparrel missile's console: [Ref. 8: p. 161]

A single launcher has 4 missiles and can be launched by the vessel's fire control system, for example Mk 68 GFCS.

Types of radar required for Sea Chaparrel missile:

Surveillance radar.

Type: SPS-10 air search radar.

Tracking radar.

Type: SPG-53 tracking radar.

Description: The SPG-53 is a X-band monopulse tracking radar. It has low-elevation angle tracking capability via clutter cancellation and employs a monopulse technique. It incorporates both spiral 12 degree scan for acquisition and conical 3 degree scan for tracking. It can track out to 360,000 ft

[Ref. 14: p. 179], and also incorporates continuous wave for secondary missile control. The SPG-53 has a 250 kw transmitter with 30 ft accuracy and 240 ft resolution.

Launch Weight. [Ref. 24: p. 40]

194.7 lb (88.5 kg)

2. Propulsion

Launch and cruise by solid propellant rocket. [Ref. 24: p. 40]

3. Warhead Section

Type of Warhead: [Ref. 17: p. 48] [Ref. 24: p. 40],

Continuous Rod Warhead

Weight of Warhead: [Ref. 14: p. 227]

22.4 lb (10.5 kg)

Fuze Systems: [Ref. 24: p. 40]

Active infra-red (IR) proximity Fuze

Damage Mechanism: [Ref. 24: p. 64]

The rods. Approximate initial velocity of the rods is 1,000 to 1,400 m/sec.

Explosive Type:

High Explosive (HE) Warhead

4. Target Detection, Tracking, and Missile Guidance

The Sea Chaparrel is a Basic Point Defence System (BPDS) missile. The missile is designed to intercept helicopters and high speed aircraft at low altitude and sea-skimmer missiles. In this circumstance, target designation is performed by air search radar, SPS-10 air search radar. Then all information is passed to the SPG-53 tracking radar which locks onto target. When the target comes into the missile's range, the missile is launched and guided by the passive IR homing guidance system which homes in (closes) on the heat generated by the target.

Type of guidance: [Ref. 17]

Passive infra-red homing

Type of Navigation:

no information available

5. Performance

Speed: [Ref. 8: p. 161]

Mach 3.0

Minimum/Maximum Range: [Ref. 14: p. 226]
max. 11 mi (17.7 km)

Minimum/Maximum Altitude: [Ref. 27: p. 487]

max. 3,000 ft (914 m)

Target Maneuverability:

no information available

Target Destructibility:

no information available

Sea Chaparrel vs SPG-53

Tracking in X-band (10 GHz), $\lambda = 0.03$ m

$R_{max} = 112$ km

Fig. 3.8 shows the maximum radar range and the maximum and minimum missile range versus target altitude

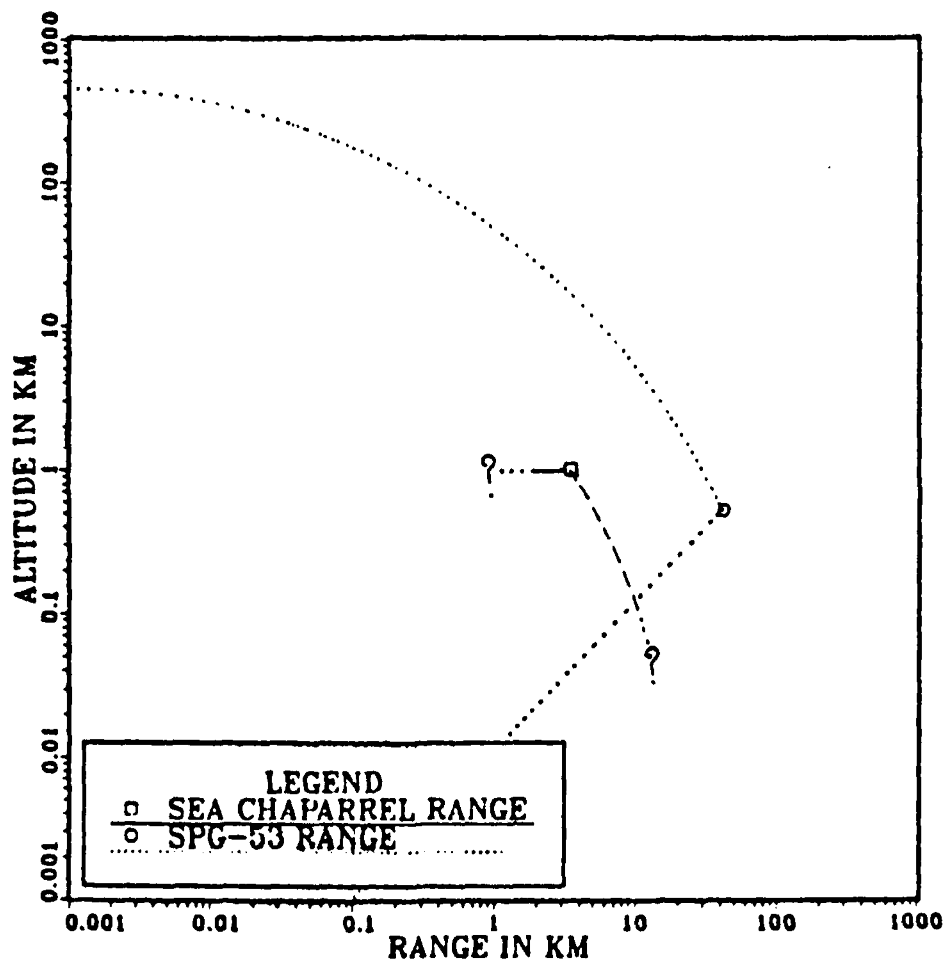

Figure 3.8 Comparison of Sea Chaparrel Missile and SPG-53 Tracking Radar.

TABLE 3

Comparison of the Missile Specifications in the US Navy

Missile	Dimension L m	Dimension Dia mm	Dimension Span mm	Propulsion	Guidance Guidance	Guidance Navigation	Launch Weight (kg)	Warhead Weight kg	Warhead Type	Speed Mach	Range Min m	Range Max m	Intercept Min m	Intercept Max m	Remarks
Tartar	4.6	343	1060	Solid prop. rocket motor	SARH	Prop. Nav.	646	53.2 54.5	Fragmentation	2.8	16000	40000	300	12000	RIM-24A RIM-24B
Terrier	8.25	343	1170	solid fuel booster and	Beam riding	-	1315	99	Controlled fragmenta-	1.8	-	19300	50	24400	RIM-2A
	7.98	343	1070	sustainer	SARH	-	1390	125	tion	2.5	-	74000			RIM-2F
SM1-MR	4.47	343	914	Solid prop. motor Mk56 Mod0	SARH	-	581	125	Fragmentation war.	2.5	-	30600	18	24400	
SM1-ER	7.93	343	914	1/Mk12 booster, 1/Mk30 sustainer	SARH	-	1344	-	Fragmentation	2.5	-	56300	15	24000	
SM2-MR	4.47	343	914	Solid prop. booster, fluid-fuel ram.	SARH	Inertial	581	-	Fragmentation	2.5	-	48300	45	18000	
SM2-ER	7.98	343	914	1/Mk12 booster, 1/Mk30 sustainer	SARH	Inertial	1359	-	Fragmentation war.	2.5	-	121000	-	>20000	
RAM	2.79	127	610	1/MK36 Mod7 solid propellant rocket	Passive RF in midcourse & IR in terminal	Prop. Nav.	72	10.2	Frag with smooth casing and roof-shaped inserts or profiled charge.	2.5	-	3200	3	>100	or passive IR all the way
Sea Sparrow/ NATO Sea Sparrow	3.66	203	1020	1/Mk56 Mod2 solid propellant rocket	SARH	Lead Angle	227	41	Continuous rod	2.5	22000	25000	5	5000	
Sea Chaparrel	2.37	127	630	Solid propellant rocket	IR homing	-	88.5	10.5	Continuous rod	3.0	-	17700	-	914	

IV. FRENCH NAVY

The surface-to-air missiles in the French Navy are:

1. MASURCA Missile.
2. NAVAL CROTALE Missile.
3. SADRAL SEA-TO-AIR Missile.
4. STANDARD SM1-MR Missile.

A. MASURCA

The Masurca is a medium-range, tandem two-stage antiaircraft weapon system. The missile has a cylindrical body with a pointed nose and pivoted cruciform tail control surfaces in line with long-chord narrow wings. Powered by a tandem, solid propellant booster with four large fins, four fixed rear fins with ailerons for roll-control and four hydraulically driven canard nose control and a solid end burning sustainer, it is launched from a twin (dual) arm launcher and carries a proximity fuzed high-explosive warhead. This missile can intercept supersonic targets at a range of 21.5 nmi (40 km) or more.

Originally, two types of guidance were employed: radio command and semi-active radar homing for the Mk 2 Mod 2 and Mod 3, respectively. However, only the Mk 2 Mod 3 missile is in service [Ref. 7: p. 96]. Mod 3 has a receiver aerial at the front whose signals are compared with signals received directly from the ship at two horns in the rear. These received signals provide the doppler velocity which enables proportional navigation to be used in the interception. Externally, the two versions are virtually identical to each other and both use the same complete shipboard installation. Each of the Masurca ships is equipped with a

three-dimensional (3-D) surveillance radar (DRBI 23) [Ref. 7: p. 490], a weapon director, and a twin (dual) arm launcher.

1. <u>Physical Description</u>

Dimensions. [Ref. 7], [Ref. 14]

Length: 338.0 in (8.6 m) with booster.

208.3 in (5.29 m) without booster.

Diameter: 0.406 m (+0.57 m booster)

Span: 59.0 in (1.5 m)

Systems.

Launchers: [Ref. 7]

A twin (dual) arm launcher.

The French ships fitted with the Masurca missile are: [Ref. 7], [Ref. 11], [Ref. 19]

1. 2 Aircraft Carriers (Clemenceau, Foch) with one twin (dual) arm launcher with a magazine capacity for 48 Masurca missiles.
2. 2 Suffren Class with one twin (dual) arm launcher with magazine capacity for 48 Masurca missiles.
3. 1 Colbert with one twin (dual) arm launcher with a magazine capacity for 48 Masurca missiles.

The Masurca missile's console: [Ref. 19: p. 104]

A twin (dual) arm launcher for Masurca missile has the correction data system for fire control from SENIT 1 tactical data system.

Types of radar required for Masurca missile:

Surveillance radar.

Type: DRBV-20 long range air search radar.
DRBI 23 3-D air search radar.
DRBI-10 height-finding radar.

Tracking radar.

Type: DRBR-51 tracking/illuminating radar.

Description: The DRBR-51 consists of a pair of antennas, a large diameter unit is a C-band 5 cm wavelength target-tracker which can also measure the deviation of the missile from the line-of-sight to the target, and a small diameter for command transmission. Meanwhile, a third antenna operating in J-band is used to generate the initial gathering beam. The main dish is fitted for CW Injection for semi-active operation.

Launch Weight. [Ref. 14]

4,585 lb (2,080 kg) with booster.
2,359 lb (1,070 kg) without booster.

2. Propulsion

Launch: A solid propellant booster

Cruise: A solid fuel end burning sustainer.

3. Warhead Section

Type of Warhead: [Ref. 14]

Continuous Rod Warhead

Weight of Warhead: [Ref. 14]

265 lb (120 kg)

Fuze System: [Ref. 14]

Proximity Fuze

Damage Mechanism:

The rods. Approximate initial velocity of the rods is 1,000 to 1,400 m/sec [Ref. 24: p. 164].

Explosive Type: [Ref. 14]

High Explosive (HE) Warhead

4. Target Detecting, Tracking, and Missile Guidance

Masurca is a medium range missile. The guidance system is Mk 2 Mod 3 with a semi-active radar homing (SARH) using the Thomson-CSF DRBR-51 tracking radar which has 3 antennas. The missile intercepts the target using the proportional navigation law. The long range target is detected by a surveillance radar, DRBV-20 or DRBI-23; whereas more precise target location is done by a height finding radar, DRBI-10. As the target comes into range, it

will be tracked and locked on by the DRBR-51 fire control radar. For this system, both the target and the missile are continuously tracked by DRBR-51. When firing the Masurca Mk 2 Mod 3, the main dish of of the DRBI-51 is used to track and continuously follow the target. A small diameter antenna transmits the necessary command signals to the missile to keep it within line-of-sight, while the third antenna is a J-band target illuminator radar whose function is to illuminate the target and missile.

Type of Guidance: [Ref. 14]

Semi-active radar homing (SARH)

Type of Navigation: [Ref. 7: p. 129], [Ref. 14]

Proportional Navigation

5. Performance

Speed: [Ref. 14], [Ref. 19]

Mach 3.0

Minimum/Maximum Range: [Ref. 14], [Ref. 19]

max. 31 mi (50 km)

Minimum/Maximum Altitude: [Ref. 19]

100 - 75,000 ft (30 - 22,860 m)

Target Maneuverability:

no information available

Target Destructibility:

no information available

TABLE 4

Comparison the Missile Specifications in the French Navy

Missile	Dimension			Propulsion	Guidance		Launch Weight	Warhead		Speed	Range		Intercept		Remarks
	L m	Dia mm	Span mm		Guid-dance	Navig ation	(kg)	Weight kg	Type	Mach	Min m	Max m	Min m	Max m	
Masurca	8.6	976	1500	Solid prop. booster and solid fuel sustainer	SARH	Prop. Nav.	2080	120	Continuous rod	3.0	-	50000	30	22860	
Naval Crotale	2.93	156	540	Solid prop. rocket motor	Radio comm.	CLOS	80	15	Shaped charges or directed fragments	2.35	500	11000	500	3630	range a/c
											500	13000	-	-	range heli
											500	6000	4	-	range sea-skimmer
Sadral	1.81	90	-	DB prop. booster and composite prop sustainer	Passive IR homing	-	20	3	Fragmentation/Blast	2.6	300	6000	-	-	
SM1-MR	7.98	343	914	1/Mk12 booster, 1/Mk12 sustainer	SARH	-	1344	-	Fragmentation	2.5	-	30600	18	24400	

Target Destructibility: [Ref. 29]

The Sadral permits destruction capability for miss distance less than or equal one. However, no information is available for kill probability.

D. STANDARD SM1-MR

The Standard SM1-MR missile in the French Navy has the same specifications and missile guidance system as used in the US Navy. The French ships fitted with the Standard SM1-MR missile are:

1. 4 Kersaint Class, Corvetted T-47 Type with 1 single arm Mk 13 launcher with a magazine capacity for 40 Standard SM1-MR missiles. [Ref. 19]
2. 3 C-70 Type, AAW Corvettes[23] with 1 single arm Mk 13 launcher aft. with a magazine capacity for 40 Standard SM1-MR missiles. [Ref. 31]
3. Georges Leygues (C-70 Type, ASW phototype)[24] with 1 single arm Mk 13 launcher with a magazine capacity for 40 Standard SM1-MR missiles.

---

[23]They were authorized under the 1977-82 plan, for completion from 1988 onward.

[24]It was delivered in 1979, and the last at least seven will not be completed until after 1988.

sea-skimmer missiles. According to the situation, target designation may be performed by using not only the ship's surveillance radar or an optronic surveillance system (either IR or optical), but also simpler systems such as the navigation radar. The missile uses passive anti-radiation homing for the midcourse phase, reverting to passive IR homing only in the terminal phase which the missile homes in on the heat generated by the target. [Ref. 32]

Type of Guidance: [Ref. 30]

Passive Infrared Homing Guidance

Type of Guidance:

no information available

5. Performance

Speed [Ref. 7: p. 13], [Ref. 32]

Mach 2.6

Minimum/Maximum Range: [Ref. 32]

300 - 6,000 m

Minimum/Maximum Altitude:

no information available

Target Maneuverability:

against a target maneuvering up to 8-g [Ref. 32]
against aircraft at speeds up to 900 mph [Ref. 30]

Launch Weight. [Ref. 30]

44 lb (20 kg)

2. Propulsion

Booster-sustainer motor

Launch: DB propellant booster

Cruise: Composite propellant sustainer

3. Warhead Section

Type of Warhead: [Ref. 32]

Blast/Fragmentation Warhead

Weight of Warhead: [Ref. 29], [Ref. 30], [Ref. 32]

6.6 lb (3.0 kg)

Fuze System: [Ref. 29]

Active laser proximity fuze with precise distance cut-off.

Damage Mechanism: [Ref. 29]

Tungsten ball fragments.

Explosive Type: [Ref. 29], [Ref. 30]

High Explosive (HE) warhead

4. Target Detecting, Tracking, and Missile Guidance

Matra Sadral is a very short range surface-to-air missile system. The missile is designed to intercept helicopter and high speed aircraft flying at low altitude and

2. Georges Leygues (C-70 Type, ASW phototype)[21] with two Sadral lightweight launchers.
3. 3 C-79 Type, AAW corvettes[22] with two Sadral lightweight launchers.

The Sadral system's console:

The ship systems contains six firing tubes mounted on an orientable turret.

Types of radar required for Sadral missile system:

Surveillance radar.

The Sadral system can use ship's surveillance radar systems. [Ref. 29]

Type: DRBJ-11B rotating phased array radar DRBV-15 air/surface surveillance radar or electronic surveillance system (infrared or optical)

Tracking radar.

Type: A video picture from a TV camera mounted on the mobile part of the carriage (in bearing and elevation). A thermal (infrared) camera is optionally envisaged for night firing.

---

[21] She was delivered in 1979 and the last of at least seven will not be completed untill after 1988.

[22] They were authorized under the 1977-1982 plan, for completion from 1988 onward.

guidance, employing a passive system that is claimed to be very sensitive and capable of true "fire-and-forget" operation. Impact and proximity fuzing is provided for the 3 kg warhead (1 kg HE), and the IFF module is available to prevent engagement of friendly aircraft and minimize reaction time in the face of enamy targets. The Satcp missile is, essentially, composed of a rocket motor, a passive infra-red homing head, pilot and guidance electronics, an electrical servo motor actuating a pair of canard control surfaces, a primable thermal battery supplying electrical power to airborne equipment, a warhead, an active proximity fuze, and a warhead-arming and safety device. The canard type aerodynamic configuration gives the missile great maneuverability, permitting it to counter successively any evasive target action, even extended targets maneuvering up to 8-g.

1. <u>Physical Description</u>

Dimensions. [Ref. 29]

Length: 5.93 ft (1.81 m)

Diameter: 3.54 in (90.0 mm)

Systems.

Launchers: [Ref. 29], [Ref. 30]

A six Satcp rounds launcher.

The French ships fitted with the Sadral SAM launcher are: [Ref. 31]

1. Charles de Gaulle aircraft carrier with two Sadral lightweight launchers.

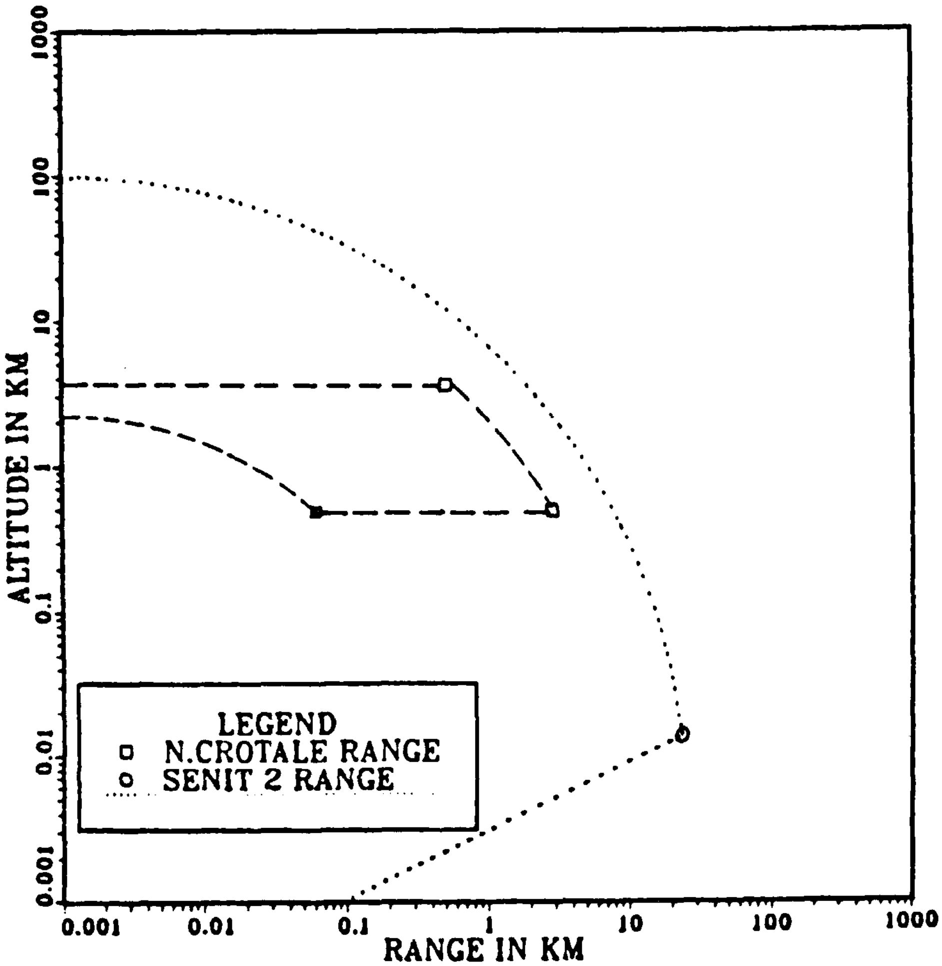

Figure 4.2 Comparison of Naval Crotale Missile and SENIT 2 Fire Control Radar.

C. SADRAL SEA-TO-AIR MISSILE SYSTEM

The Sadral system with the Satcp missile is a very short range anti-aircraft system carried by surface vessels. It consists of a package of six Satcp missiles. The missile is designed to intercept helicopter and high speed aircraft flying at low altitude and can be used against missiles of the sea-skimmer type. The missile uses infra-red homing

Target Maneuverability: [Ref. 28]

against an aircraft maneuvering at 2-g at 8.5 km
against sea-skimming at speeds of up to 600 m/s (1,335 mph) or Mach 1.75 at sea level.

Target Destructibility:

Single Shot Kill Probability, Pkss = 0.75 [Ref. 14: p. 183], [Ref. 17: p. 37]
Two-round salvos Kill Probability = 0.96 [Ref. 7: p. 97]

Naval Crotale vs SENIT 2 Fire Control Radar

Assume:

Tracking in C-band (6 GHz), $\lambda = 0.05$ m

Antenna diameter, d = 6 ft
Antenna area, A = 2.60 sq.m
Receiver bandwidth, B = 1 MHz
Noise figure, F = 4.6 dB = 2.88 (from fig. 2.3)
$(S_o/N_o)_{min} = 14.7$ dB = 29.51
From equation 2.16; $S_{min} = 3.35 \times 10^{-13}$ watts

Assume:

For an antenna efficiency, $\rho = 0.85$, $A_e = 3.97$ sq.m
For a target cross section 1 sq.m, n = 31, and Ls = 20
Average power, $P_t = 1$ KW

From equation 2.18; $R_{max} = 24$ km

Fig. 4.2 shows the maximum radar range and the maximum and minimum missile range versus target altitude.

command guidance and are sent to the missile receiver at the front by a radio signal.

The specific path along which the missile is navigated is determined the line-cf-sight between the target tracking unit and the target. This is known as command to line-of-sight (CLOS). Thereafter, the missile course is gathered by the IR system with 5 degree vision and stand-by TV and optical tracking if radar command is impossible, and slaved to the 1.1 degree J-band beam which is locked on to the target.

Type of Guidance: [Ref. 7], [Ref. 14], [Ref. 19]

Radio Command Guidance

Type of Navigation: [Ref. 17: p. 37]

Command to line-of-sight (CLOS)

5. Performance

Speed: [Ref. 14]

Mach 2.35 (800 m/sec at sea level)

Minimum/Maximum Range: [Ref. 7]

500 - 11,000 m (aircraft)
up to 13,000 m (helicopter)
up to 6,000 m (sea-skimmer)

Minimum/Maximum Altitude:

500 - 3,600 m [Ref. 17: p. 37]
Intercept incoming sea-skimming missiles at 4 m (13.12 ft) above sea surface. [Ref. 28]

Explosive Type:

High Explosive (HE) warhead

4. Target Detecting, Tracking, and Missile Guidance

Naval Crotale is a surface-to-air, radio command guidance type with a command to line-of sight guidance system. The incoming target is identified by the LMT IFF air surveillance radar or by the DRBV-26 D-band low-flying surveillance radar. The location, velocity, and bearing of the target are passed on to the Senit 2 computer fire control system in the control room. The fire control room has Senit data processing and display. Engagement can be automatic or manual.

Tracking is performed by the Senit 2 radar system. After the Naval Crotale unit locks on the target, the missile is launched by the operator in the fire control room. Steering signals, based on the position of the missile with respect to the center (or the scanning axis) of the tracking beam, are computed by the Senit 2 computer fire control system and sent to the missile control surfaces. A radar beacon or infra-red flare on the tail of the missile provide information to the tracking system on the location of the missile. The target and missile range, elevation, and bearing are continuously fed to a computer. Using the position and position rate information, the Senit 2 computer determines the flight path the missile should take that will result in detonating the high explosive warhead near the target. It compares this computed flight path with the predicted flight path of the missile based on current tracking information and determines the correction signals required to move the missile control surfaces to change the current flight path to the new one. These signals are the

Types of radar required for Naval Crotale missile:

Surveillance radar.

Type: DRBV-26 low-flyer air search radar. DRBV-51C with MTI, LMT IFF air search radar.

Tracking radar.

Type: SENIT 2 fire control system.

Launch Weight. [Ref. 14], [Ref. 19]

185 lb (80 kg)

2. Propulsion

Double Base (DB) propellant with single solid propellant rockets (SR) motor. (booster-sustainer design)

3. Warhead Section

Type of Warhead: [Ref. 14]

Shaped Charge or Directed Fragments

Weight of Warhead: [Ref. 14]

33 lb (15 kg)

Fuze System: [Ref. 7], [Ref. 14], [Ref. 19]

Infra-red Proximity Fuze

Damage Mechanism:

Penetrators or fragments

1. <u>Physical Description</u>

Dimensions. [Ref. 14], [Ref. 19]

Length: 178.3 in (2.93 m)

Diameter: 6.14 in (156.0 mm)

Span: 21.25 in (540.0 mm)

Systems.

Launchers: [Ref. 14]

An eight-round launcher.

The French ships fitted with the Naval Crotale missile are: [Ref. 14]

1. 2 Helicopter Carrier with two launchers.
2. 16 C-70 Type with one launcher with a magazine capacity for 26 Naval Crotale missiles.
3. 3 F-67 Type with one launcher with a magazine capacity for 26 Naval Crotale missiles.

The Naval Crotale missile's console: [Ref. 7]

A combined mounting (air and surface) on with a two axis stabilized radar director and eight-round launcher; the radar director also carries the guidance transmitter antenna, two infra-red sensors, and a television camera.

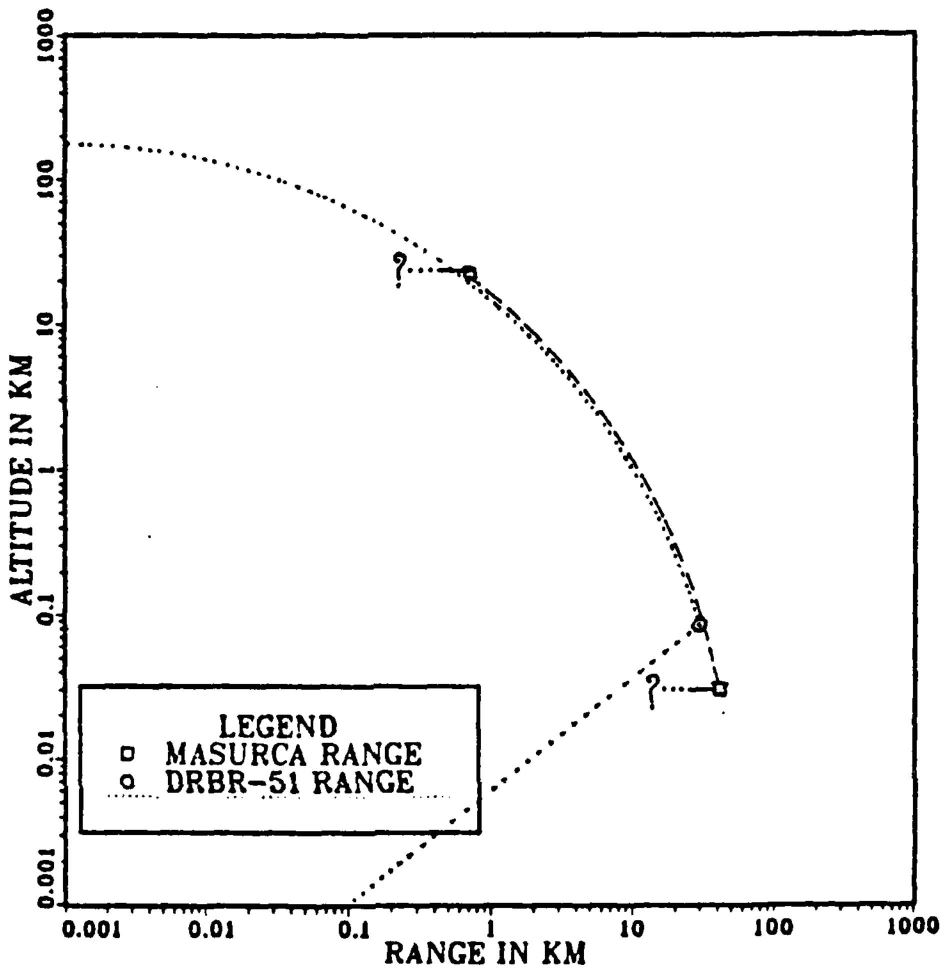

Figure 4.1 Comparison of Masurca Missile and DRBR-51 Tracking Radar.

antenna and other sensors for tracking and command operation. The launcher turret carries eight rounds.

After launching, the missile is automatically guided onto the line-of-sight by an infra-red system, and thereafter is guided by commands from the ship-based radar tracker [Ref. 17: p. 37]. In addition, television tracking can also be used if necessary at low angles of fire.

Masurca vs DRBR-51

Tracking in C-band (6 GHz), λ = 0.05 m

Assume:

Antenna diameter, d = 2.44 m

Antenna area, A = 4.67 sq.m

Receiver bandwidth, B = 1 MHz

Noise figure, F = 4.6 dB = 2.88 (from fig. 2.3)

$(S_o/N_o)_{min}$ = 14.7 dB = 29.51

From equation 2.16; $S_{min} = 3.35X10^{-13}$ watts

Assume:

For an antenna efficiency, ρ = 0.85, A_e = 3.97 sq.m

For a target cross section 1 sq.m, n = 31, and Ls = 20

Average power, P_t = 5 KW

From equation 2.18; R_{max} = 46 km

Fig. 4.1 shows the maximum radar range and the maximum and minimum missile range versus target altitude.

B. NAVAL CROTALE

The Naval Crotale is a naval basic point defence missile system. Guidance commands come from a radar tracker to steer an 80 kg missile at range up to 8.5 km (4.6 nmi) [Ref. 17: p. 37]. Target designation data can be accepted from the ship's Central Operation Room or Fire Control Room. The ship's search radar (i.e. DRBV-26, DRBV-51C) [Ref. 14], optical or infra-red trackers or other systems can be used to lay the Naval Crotale fire unit onto the target. Only one operator is required at the Crotale console which links

V. ROYAL NAVY

The surface-to-air missiles in the Royal Navy are:

1. SEACAT Missile.
2. SEA DART/LIGHTWEIGHT SEA DART Missile.
3. SEAWOLF/LIGHTWEIGHT SEAWCLF Missile.
4. SLAM Missile System.
5. SEASLUG Missile.

A. SEACAT

Seacat was the first shipboard system designed for close-range defence as a replacement for rapid-fire guns. It is a close-range, shipborne, subsonic, guided missile system for anti-aircraft defence which may also be used against surface targets within visual range. The missile has a dual thrust solid motor, four fixed tail fins, hydraulically driven wings clipped around the square-section fore-body, potted guidance packs, and a relatively large continuous rod warhead with direct action (DA) and proximity fuzes. The guidance system is based on the use of optical tracking and a radio link. The latest Seacat has a height control facility which allows the missile to be flown to 2 meters above the sea or at prcgrammed sea-skimming levels against low-level targets, including light craft and sea-skimming missiles, or shore-based installations, without danger of ditching. The height control provides a cushion between the missile and the sea, with clearance distance automatically adjusted to minimize the danger of ditching regardless of the sea state encounted. The cruise height can be selected between 2 meters and 10 meters depending on the sea state and type of target. Once the missile is

cruising smoothly, the operator switches from a 22.5 degree field of view to 5.5 degree and continues to steer the missile in azimuth until impact.

The reduced maneuvering resulting from the use of height control extends Seacat's maximum range to 7 km, compared with 5 km for the surface-to-air version. The minimum range is 500 m. The missile's 18-kg warhead is sufficient to disable small ships, and the proximity fuze is effective over a range of 15 m.

The basic form of the system, as Guided Weapon Systems Mk 20 (GWS 20), adopted by the Royal Navy uses a "dustbin" housing for the operator who tracks the missile after launch through binoculars and sends steering commands by a thumb joystick control to keep the missile on the line-of-sight to the target. The more recent GWS 22 fire control systems links a tracking radar to the operator's sight. The weapon is also linked in various installations to foreign radars, such as the Contraves SeaHunter, SanGiogio NA9. A light-weight, three-round launcher (based on the short Tigercat launcher) is available for light craft, such as minesweepers and fast patrol craft, in order to provide guided-weapon defence against low flying aircraft.

1. Physical Description

Dimensions. [Ref. 14]

Length: 4.86 ft (1.48 m)

Diameter: 7.5 in (190.5 mm)

Span: 2.13 ft (650.0 mm)

Systems.

Launchers: [Ref. 33]

A standard four round launcher.

The Royal Navy ships fitted with the Seacat missile are: [Ref. 33]

1. 1 Hermes with two 4-round launchers.
2. 3 County Class with two 4-round launchers.
3. 6 GP Frigates Type 2 Class with one 4-round launcher.
4. 5 Leander Class with three 4-round launchers.
5. 8 Leander Class with two 4-round launchers.
6. 7 Rothesay Type 12 Class with one 4-round launcher.
7. 3 Tribul Type 81 Class with two 4-round launchers.
8. 2 Assualt (LPD) ships with four 4-round launchers.

The Seacat missile's console: [Ref. 19]

Guided Weapons System Mk 20 (GWS 20) for optical systems or GWS 21, GWS 22, GWS 24 for radar systems.

Types of radar required for the Seacat missile: [Ref. 7], [Ref. 13], [Ref. 19]

Surveillance radar.

Type: Type 994 S-band search radar

Tracking radar.

Type: Type 904 tracking radar

Description: Type 904 is I/J-band frequency with conical scan tracking radar. The latest version is equiped with a Marconi television system aligned with the radar bore sight for missile guidance.

Launch Weight. [Ref. 14]

143 lb (65 kg)

2. Propulsion

Dual thrust solid motor

3. Warhead Section

Type of Warhead: [Ref. 14]

Continuous Rod Warhead

Weight of Warhead:

45.0 lb (20.45 kg)

Fuze System: [Ref. 7]

Passive IR proximity fuze and contact fuze

Damage Mechanism:

The rods. Approximate initial velocity of the rods is 1,000 to 1,400 m/sec [Ref. 24: p. 164].

Explosive Type: [Ref. 14]

High Explosive (HE) warheadwith RDX/TNT and 38 lb (17.3 kg) weight.

4. Target Detecting, Tracking, and Missile Guidance

The missile is a radio command guidance type with the command to line-of-sight (CLOS) navigation system. The incoming target is acquired by the Type 994 radar and is locked on by the RTN-10X tracking radar when the target is in range. There are three types of target engagements:

1. The basic form of the system is GWS 20. This consists of separate launcher and operator mounts, the latter carry sighting binoculars whose elevation is followed by the missiles. As soon as the target is acquired and within range, a missile is fired, coming into view of the tracking optics in about 7 seconds at 1,000 ft (300 m) and after that the operator still guide the missile until intercept. Manual gathering and manual guidance by the operator keeps the tracking flares on two fins lined up with the target by a command joystick.
2. The GWS 21 and GWS 22 use different Royal Navy radars to give night time fire capability. This system can engage the target as follows:

   Radar tracking, manual gathering, and manual guidance.

   Radar tracking, manual gathering using TV monitor, and manual guidance using TV monitor.

   Radar tracking, automatic gathering from TV data, and automatic guidance from TV data.

3. The GWS 24 gives blind fire capability. This system can engage the target as follows:

Radar tracking, automatic gathering from TV data, and manual guidance using radar display.

Radar tracking, automatic gathering from TV data, and automatic guidance from radar data.

Type of Guidance: [Ref. 17: p. 40]

Radio Command Guidance

Type of Navigation: [Ref. 17: p. 40]

Command to line-of-sight (CLOS)

5. Performance

Speed:

subsonic missile, 750 ft/sec (450 knot/hr)

Minimum/Maximum Range: [Ref. 21: p. 1439], [Ref. 34: p. 283]

500 - 5,000 m for the surface-to-air version
500 - 7,000 m for the surface-to-surface version

Minimum/Maximun Altitude: [Ref. 21: p. 1439], [Ref. 34: p. 283]

6.6 - 33.0 ft (2 - 10 m)

Target Maneuverability:

no information available

Target Destructibility:

no information available

B. SEA DART/LIGHTWEIGHT SEA DART

The Sea Dart (GWS 30) is an all-weather, medium-range, area-defence system designed to counter the threat posed by aircraft flying in excess of Mach 2.0 and by surface and air launched missiles. As a multi-role missile system, the Sea Dart can also be used in an anti-ship capability. Launch rate is rapid, but the weapon system was not designed to engage simultaneously many targets. The missile is launched from a twin (dual) arm Mk 30 launcher with a magazine capacity for 20 Sea Dart missiles and uses semi-active radar homing all-the-way with the proportional navigation law.

Lightweight Sea Dart is intended for ships from 300 tons upward. The Lightweight Sea Dart has been developed from the existing Sea Dart Guided Weapon System GWS 30. The performance of Lightweight Sea Dart is dependent on the capacities of the surveillance and tracking radars fitted. The ship's surveillance radar is used to provide the basic target detection and is used to point the tracking radar.

1. Physical Description

Dimensions. [Ref. 14]

Length: 14 ft 5.25 in (4.40 m)

Diameter: 16.5 in (420.0 mm)

Span: 30.0 in (960.0 mm)

Systems.

Launchers: [Ref. 19], [Ref. 33]

A twin (dual) arm launcher.

The Royal Navy ships fitted with the Sea Dart/Lightweight Sea Dart missile are:

1. 3 Invisible with a single twin (dual) arm Mk 30 launcher with a magazine capacity for 22 Sea Dart missiles [Ref. 19], [Ref. 33].
2. 1 Type 82 with a single twin (dual) arm Mk 30 launcher with a magazine capacity for 40 Sea Dart missiles [Ref. 11: p. 586].
3. 9 Type 42 with a single twin (dual) arm Mk 30 launcher with a magazine capacity for 40 Sea Dart missiles [Ref. 11: p. 588].

The Sea Dart missile's console:

Guided Weapon System Mk 30 (GWS 30) receives main command control from ADAWS 2 Action Data Automation Weapon System.

Types of radar required for the Sea Dart missile:

Surveillance radar.

Type: Type 965 2-D air search radar
Type 992 height-finding radar

Tracking radar.

Type: Type 909 tracking/illuminating radar

Description: Type 909 TIR is a G/H-band frequency range. The antenna has a diameter of 8.0 ft (2.44 m) and is of the cassegrain type. It has ECCM which are incorporated to counter both active and passive ECM.

Launch Weight. [Ref. 14]

1,210 lb (549 kg)

2. Propulsion

Tandem Integral Rocket-Liquid Fuel Ramjet Configuration

Launch: Composite double base booster

Cruise: Kerosene liquid fuel ramjet

3. Warhead Section

Type of Warhead: [Ref. 24: p. 164]

Fragmentation with externally grooved casing

Weight of Warhead:

no information available

Fuze System: [Ref. 14]

Direct Action (DA) and Proximity Fuze

Damage Mechanism:

a large number of fragments

Explosive Type:

High Explosive (HE) warhead

4. Target Detecting, Tracking, and Missile GUidance

The missile uses semi-active radar homing guidance with proportional navigation. The engagement operation begins when the incoming targets are designated generally by

the Type 965 air search radar and in a more precise fashion by the Type 992 S-band target-indicator radar. The information of the target is passed on to the ADAW 2 Action Data Automation Weapon System which sends commands to one of two tracker/illuminator radars (TIR) Type 909 to lock on to the target and illuminate it for the missile's receiver and homing system. At the same time, the ADAW 2 passes commands to the Guided Missile System Mk 30 (GWS 30) or Mk 30 Mod 2 (GWS 31) launcher, causing the launcher to follow the Type 909 radar and point at the predicted interception position.

When the target is in range, the missile is fired. The Sea Dart is accelerated off the launcher by a solid fuel rocket booster which propels it to a speed of Mach 2.0 in 2.5 seconds. The target sustainer motor then ignites, the booster is jettisioned, and the missile accelerates up to Mach 3.5.

During flight, the Sea Dart semi-active missile guidance requires target velocity data as well as direction guidance via the fire control system. In addition to tracking the target, the TIR illuminates it so that Sea Dart homes in toward the target by proportional navigation using four interferometer receiver aerials spaced around the double-shock nose inlet to pick up reflected radiation energy from the target. The missile obtains its doppler information by comparing the reflected beam with a beam transmitted directly from the Type 909 to continually update the predicted interception point.

Type of Guidance: [Ref. 14: p. 190], [Ref. 17: p. 41]

semi-active radar homing (SARH)

Type of Navigation: [Ref. 14: p. 190], [Ref. 17: p. 41]

Proportional Navigation

5. Performance

Speed: [Ref. 14: p. 60]

Mach 3.5

Minimum/Maximum Range: [Ref. 58]

30 - 50 km

Minimum/Maximum Altitude: [Ref. 17: p. 41], [Ref. 19]

100 - 82,000 ft (30 - 25,000 m)

Target Maneuverability:

no information available

Target Destructibility:

no information available

Sea Dart vs Type 909

Tracking in G/H-band (6 GHz), λ = 0.05 m

Antenna diameter, d = 2.44 m

Antenna area, A = 4.67 sq.m

Assume:

Receiver bandwidth, B = 1 MHz

Noise figure, F = 4.63 dB = 2.9 (from fig 2.3)

$(S_o/N_o)_{min}$ = 14.7 dB = 29.51

From equation 2.16; $S_{min} = 3.4 \times 10^{-13}$ watts

Assume:

For an antenna efficiency, ρ = 0.85, A_e = 3.97 sq.m

For target cross section 1 sq.m, n = 30, and Ls = 20

Average power, P_t = 1.5 KW

From equation 2.18; R_{max} = 72 km

Fig. 5.1 shows the maximum radar range and the maximum and minimum missile range versus target altitude.

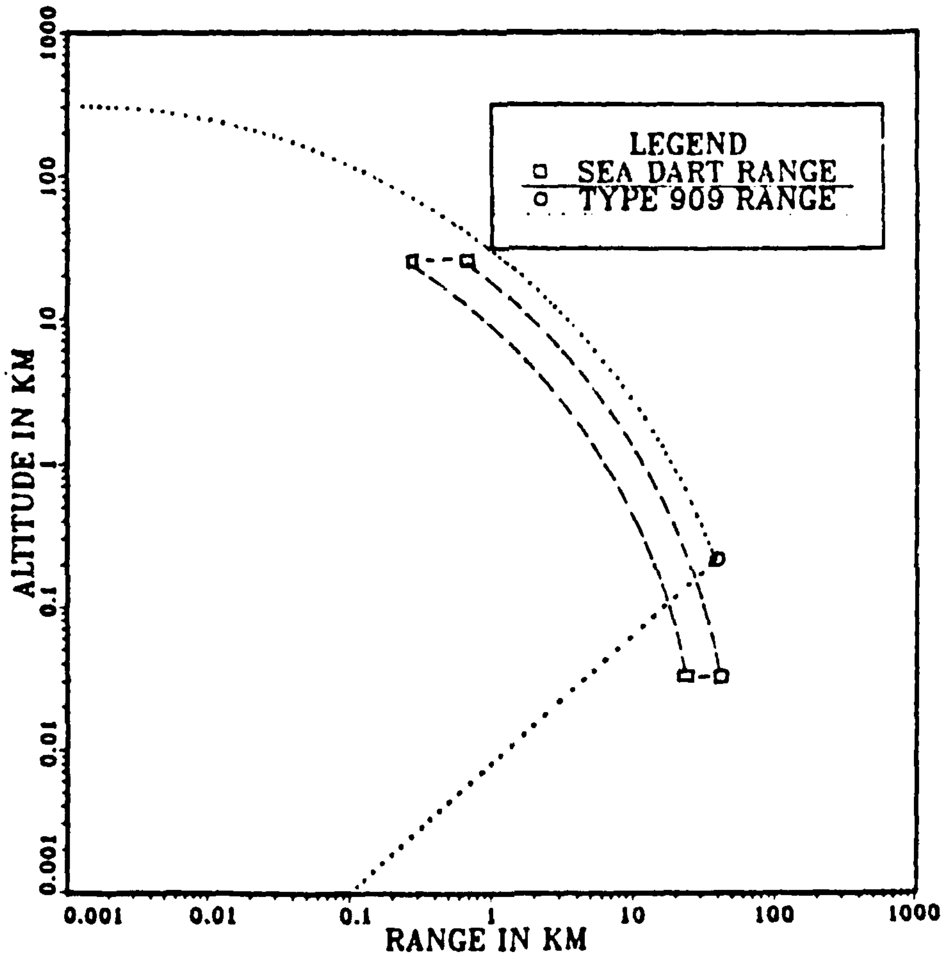

Figure 5.1 Comparison of Sea Dart Missile and Type 909 Tracking Radar.

C. SEAWOLF/LIGHTWEIGHT SEAWOLF

The Seawolf is a short-range defense system based on a fast, agile missile and a highly accurate control system capable of working in all types of weather and under cluttered conditions. The Seawolf missile employs line-of-sight guidance radar differential tracking or television, both with the radio command. The main units of the system are the surveillance radar, the tracking radar, command guidance equipment, the data handling and control system, and the launcher with missiles. The Seawolf is designed to intercept aircraft, sea-skimming missiles, and small, Mach 2 air-launched stand-off weapons in severe weather and has capability against supersonic missiles approaching at Mach 3.0. The Seawolf missile is of cruciform configuration with fixed wings and moving fins for aerodynamic control. Its length is approximately 1.9 meters and its overall weight is about 82 kg. Weighing approximately 14 kg., the fragmentation warhead is detonated by impact or proximity fuzes.

The GWS 25 Seawolf is launched from a Vickers six-barrel launcher, which is large and heavy, and with a magazine capacity for 12 Seawolf missiles. The complete GWS 25 system comprises the following units: [Ref. 7: p. 106]

Air and low-air surveillance radar, Type 967 and 968
Radar trackers, Type 910, and TV trackers
Command transmitter
Launcher and firing system
Missile and handling frame
Data handling
Guidance shaping unit
Operations consoles
Magazines

However, the new version is designed to vertical launch for the lightweight Seawolf, known as Seawolf VM40. The

launcher box has integral efflux ducts, the exhaust gases travelling up the ducts between the missile's cruciform surfaces and a magazine capacity for 49 ready-to-fire missiles. Also, the new tracking radar has two alternatives as follow:

The Marconi 850 SW tracking radar with director to produce a Seawolf system suitable for fitting in ships with displacements of less than 1,000 tonnes that can not support a full GWS 25 guidance system, called Flywolf [Ref. 36: p. 238]. The 850 SW is a lightweight, dual frequency differential tracker radar which added the millimetric wavelength DN181 Rapier Blindfire radar and elements of the original the Royal Navy GWS 25 system. The millimetric radar provides accurate tracking at low elevation.

The Anglo/Dutch VM 40 tracking radar is derived from the Hollandse Signaalapparaten, which has added-on a K-band tranceiver, command-link antenna, and a beacon receiver. In particular it gives an ability to track accurately the lowest targets by radar without the aid of a television system by application of a dual frequency band radar.

The main parts of the Seawolf VM40 system are: [Ref. 7: pp. 106-107]

Electronic System: A computer and control system interfaces automatically with the ship's action information system.

Tracker System: Application of a dual frequency band radar tracker with narrow beams virtually eliminates multipath effects, improves tracking accuracy, reduces jamming sensitivity and enables low level target tracking. A vedeo processor enables the system to look through various simultaneous types of clutter (e.g., sea clutter, rain clutter, and land clutter) giving excellent separation of incoming targets and outgoing Seawolf missiles.

2. More precise target location by the Type 277 height-finder
3. As the target comes into range, the target is designated to the Type 901M in three coordinates. The Type 901M locks on to the target, aims the lattice launcher and fires a missile as soon as the range is correct.

The Type 901M beam continually tracks the target. The guidance equipment on-board the missile includes a rearward facing antenna that senses the target tracking beam. Steering signals, that are based on the position of the missile with respect to the center (or the scanning axis) of the target tracking beam, are computed by Mk 1 or Mk 2 computer control system and sent to the tail control surfaces. These correction signals produce control surface movements intended to keep the missile as nearly as possible in the center of the coded pencil beam. The missile can be said to ride the beam; it does not see the target.

In the surface target role the same beam is used, though there are small difference in technique. It is assumed that most such targets are surface ships.

Type of Guidance [Ref. 17: p. 42]

Beam riding guidance

Type of Navigation:

no information available

5. <u>Performance</u>

Speed: [Ref. 19]

Mach 1.8

Launch Weight. [Ref. 19]

900 kg (2,000 kg with booster)

2. Propulsion

Launch: 4 wrap around solid propellant booster

Cruise: A solid propellant sustainer

3. Warhead Section

Type of Warhead:

no information available

Weight of Warhead: [Ref. 14]

297 lb (135 kg)

Fuze System:

Direct action (DA) and proximity fuze

Damage Mechanism:

no information available

Explosive Type:

High Explosive (HE) warhead

4. Target Detecting, Tracking, and Missile Guidance

A typical control sequence might be;

1. Targets are detected at long range by the Type 965 3-D surveillance radar radar.

Systems.

Launchers: [Ref. 14], [Ref. 19]

A twin (dual) arm launcher.

The Royal Navy ships fitted with the Seaslug missile are: [Ref. 19]

1. 4 County Class with one twin (dual) arm Mk 1 launcher with a magazine capacity for 30 Seaslug missiles.
2. 4 County Class with one twin (dual) arm Mk 2 launcher with a magazine capacity for 30 Seaslug missiles.

The Seaslug missile's console: [Ref. 19]

Guided Weapon System Mk 1 and Mk 2

Types of radar required for the Seaslug missile:

Surveillance radar.

Type: Type 965 air search radar with a single-mattress (AKE-1) for Mk 1 and double-mattress (AKE-2) for Mk 2. AKE-2 consisting of two AKE-1, one atop the other.
Type 277 height-finding and low flyer detector radar.

Tracking radar.

Type: Type 901M tracker group radar

Description: Type 901M operates in X-band.

Target Maneuverability: [Ref. 7]

slow moving or stationary targets

Target Destructibility:

no information available

E. SEASLUG

Seaslug is a long-range guided missile. It is a beam riding guidance missile with a 297 lb (135 kg) warhead weight with direct action (DA) and proximity fuze. Targets are detected at long range by the Type 965 air search radar and in a more precise fashion by the Type 277 height-finding radar and the Type 901 radar which is the Seaslug tracking/illuminating radar.

There are two versions of the missile, the Mk 1 and the Mk 2, the latter having a longer range and better low-altitude performance. Both missiles can be used against surface targets. The missile proper is cylindrical with a pointed ogival nose-cone and cruciform fixed mid-body wings indexed in line with cruciform pivoted tail control surfaces.

1. Physical Description

Dimensions. [Ref. 14]

Length: 19 ft 8 in (5.99 M) for Mk 1

20 ft 0 in (6.10 m) for Mk 2

Diameter: 16.1 in (409.0 mm)

Span: 4 ft 8.6 in (1.437 m)

4. Target Detecting, Tracking, and Missile Guidance

Target acquisition is by means of the attack periscope, the launcher being automatically aligned with the target in azimuth when the launcher mast is raised. The operator then seeks the target's elevation and tracks it on his TV screen. A thumb button controller, which also controls the launcher system, enables the operator to maintain the target in the screen center. He then selects and fires the missile. When the missile is fired, the thumb button controller is disconnected from the launcher control circuits. The radio-command guided missile is automatically gathered onto the line-of-sight and appears on the TV screen, at which point the operator controls its flight with the same thumb button controller. The launcher is able to continue tracking the target by means of a rate memory circuit which is built into the launcher control loop.

Type of Guidance:

Radio Command Guidance

Type of Navigation:

Command to line-of-sight

5. Performance

Speed: [Ref. 14]

Mach 1.5

Minimum/Maximum Range: [Ref. 17: p. 44]

max. 3,000 m

Minimum/Maximum Altitude: [Ref. 17: p. 44]

max. 2,000 m

TV camera, missile control equipment, and gyro sub-system for launcher stabilization. The launcher is retractable into a pressure vessel ensuring integrity while the submarine is dived.

Type of radar required for SLAM missile system:

TV sight system and guidance electronics

Launch Weight. [Ref. 14]

24.5 lb (11.0 kg)

2. Propulsion

Solid Propellant Rocket motor [Ref. 7], [Ref. 14]

3. Warhead Section

Type of Warhead: [Ref. 5], [Ref. 24: p. 164]

Fragmentation with smooth fragment casing

Weight of Warhead: [Ref. 7: p. 143], [Ref. 14]

4.85 lb (2.2 kg)

Fuze System: [Ref. 7: p. 143]

Impact or Proximity fuze

Damage Mechanism:

a large number of fragments

D. SLAM MISSILE SYSTEM

The Submarine-Launched Airflight Missile (SLAM) is designed to defend submerged submarines against slow aircraft and surface craft. The system uses the Blowpipe missile which was originally developed as a man-portable anti-aircraft missile. The SLAM launcher consists of six BLOWPIPE missiles grouped round a central electronics and TV unit which is used as the "eye" of the system for missile guidance. The system tracks, fires, and guides the missile by the operator who uses the periscope for control by means of a remote control TV system.

1. Physical Description

Dimensions. [Ref. 14]

Length: 55.1 in (1.40 m)

Diameter: 3.0 in (76.0 mm)

Span: 10.8 in (274.0 mm) (tail fins)

Systems.

Launchers: [Ref. 14]

A single 6-round launcher.

The Royal Navy ship fitted with the SLAM system is: [Ref. 41]

Oberon Class submarine with a single launcher.

The SLAM missile's console:

The launcher carries six BLOWPIPE missiles clustered round a watertight housing with a

Ls = 20

Average power, P_f = 5 KW

From equation 2.18; R_{max} = 30 km

Fig. 5.2 shows the maximum radar range and the maximum and minimum missile range versus altitude.

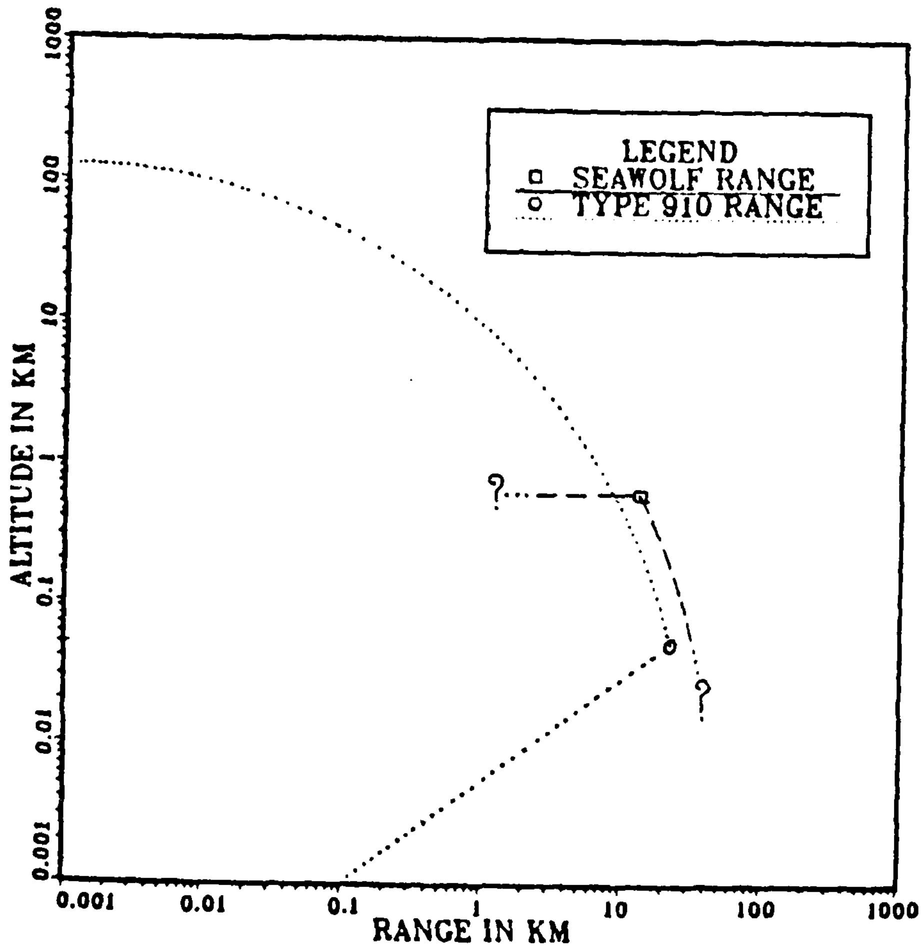

Figure 5.2 Comparison of Seawolf Missile and Type 910 Tracking Radar.

Type of Navigation: [Ref. 7: p. 517], [Ref. 38: p. 76]

Command to line-of-sight (CLOS)

5. <u>Performance</u>

Speed: [Ref. 28], [Ref. 40]

Mach 2.0

Minimum/Maximum Range: [Ref. 40]

max. 2.5 nmi (4,630 m)

Minimum/Maximum Altitude: [Ref. 7: p. 107]

intercept 2,000 ft (600 m) above sea level

Target Maneuverability: [Ref. 39]

Seawolf can engage Mach 3 missile and aircraft

Target Destructibility: [Ref. 40]

Single Short Kill Probability, Pkss is reported to be greater than 80 %.

Seawolf vs Type 910

Tracking in I/J-band (15 GHz), λ = 0.02 m

Assume:

Antenna diameter, d = 1 m
Antenna area, A = 0.79 sq.m
Receiver bandwidth, B = 1 MHz
Noise figure, F = 4.30 dB = 2.69 (from fig 2.3)
$(S_o/N_o)_{min}$ = 14.7 dB = 29.51
From equation 2.16; $S_{min} = 3.18 \times 10^{-13}$ watts

Assume:

For an antenna efficiency, ρ = 0.85, A_e = 0.67 sq.m
For target cross section 1 sq.m, n = 30, and

tracking for the target and the Seawolf missile. The tracker computer calculates the launcher angle necessary to direct the direct missile into the gathering beam.

Once the tracker locks on to the target it starts tracking, with the surveillance radar continually supplying an update of information, until the end of engagement. The launcher is instructed by the data handling computer, Ferranti FM 1600B, to point at the target and the system is ready to fire some five to six seconds after tracker allocation. When Seawolf is launched, the Type 910 tracks its target using two I-band beams while the missile location is derived from I-band beacon signal from the missile. The difference between missile flight path and beam centerline is measured 100 times a second, and a course modification is transmitted to the missile to bring it to the line of sight to the target. Furthermore, there are two command dishes operating at slightly different frequencies to reduce the effects of land and sea clutter and the multipath echoes.

Since the GWS 25 Mod 0 relative wide tracking radar beam is ineffective below 1.5 degree elevation, a TV tracker is provided for use against low-level targets. Therefore, Marconi Radar exhibited a model of the GWS 25 Mod 1 tracking array that improves low-angle tracking in ships fitted with the GWS 25 Mod 0. The Mod 0 uses the Type 910 centrimetric tracking radar plus a TV system, which is inherently weather-limited. In the Mod 1, however, the TV camera is replaced by the Rapier Blindfire DN181 millimetric differential-tracking radar, the whole being designated Type 911. Deletion of the TV would permit the removal of smoke inhibitors in the missile propellant, improving burning efficiency and hence missile performance.

Type of Guidance: [Ref. 7: p. 517]

Microwave Radio Command Guidance

Damage Mechanism: [Ref. 38: p. 77]

High spherical shaped blast wave produced by the detonation of the high explosive (HE) charge.

Explosive Type:

High Explosive (HE) Warhead

4. Target Detecting, Tracking, and Missile Guidance

The Seawolf missile has command to line-of-sight navigation with radar differential tracking, or an operator may view the target via a television tracker and aim the missile to an impact point, both with radio command. The engagement event begins when the ship's surveillance radar Type 967 L-band air search radar, or the Type 968 S-band for low air-cover and surface search radar, detects all the approaching targets. The IFF system simultaneously identifies those which are potentially hostile and then the ship's computer measures the incoming target velocity, bearing, and range. The surveillance data handling system, a digital computer, allocates a tracker to the most threatening target and feeds it with track coordinates. The Type 910 tracker group has one main dish and two side auxiliary dishes, all circular and operating in the I/J-band, it uses electronic angle tracking (EAT) to give precise and smooth tracking.

Within two or three seconds of a target being detected, the data from the search radar is passed on to the computer-controlled tracking system which then commands the launcher to pick up the missile, slews the tracker to the correct bearing, and commences a search in elevation, bearing, and velocity leading to target acquisition and lock on. If the target is approaching at low level, the system switches to the television equipment which provides separate

and lower portions which provide accurate tracking at low sight angles against targets close to the sea surface. The radar uses differential tracking for simultaneous target and missile tracking. An electronic angle tracking (EAT) receiver incorporated within the tracker detects both boresight errors for accurate positioning of its own antenna and the angular difference between the missile and the target. Commands are automatically transmitted to the missile to guide it to the line of sight.

Launch Weight. [Ref. 14]

180 lb (82 kg)

2. Propulsion

Tandem-Integral Rocket-Liquid Fuel Ramjet configuration and a tandem boost motor with integral thrust vector control for Lightweight Seawolf.

3. Warhead Section

Type of Warhead: [Ref. 39], [Ref. 40: p. 107]

Blast fragmentation

Weight of Warhead: [Ref. 14]

31 lb (14 kg)

Fuze System: [Ref. 39]

Proximity and Contact Fuze

Types of radar required for the Seawolf/Lightweight Seawolf missile are:

Surveillance radar.

Type: Type 967 and 968 L-band and S-band pulse doppler surveillance radar

Tracking radar.

Type: Type 910 tracking radar
TV tracker
Type 911 tracking radar

Description: Type 910 is a monopulse, I/J-band, differential tracker radar incorporating electronic angle tracking (EAT) receiver for small angle and maximum accuracy. This is a self-adaptive system which is capable of controlling and directing a number of Seawolf missiles to interception with only one target. It is mounted on a stabilized, tightly controlled director fitted with a TV tracking system for low angle engagements. The missile command transmitter aerials are also mounted on the director.

Type 911 is the Marconi 850 SW for the lightweight Seawolf. The radar is I-band and Ka-band [Ref. 38: p. 77] millimetric wave (dual) frequency differential tracking system which includes a command link to control the Seawolf missile during flight. The I-band antenna uses fast fourier transform techniques to ensure effective operation in severe clutter environments. The millimetric Ka-band antenna has the upper

Launcher System: The launcher can be reloaded automatically from a vertically below-deck ready-use magazine.

1. Physical Description

Dimensions. [Ref. 14]

Length: 75.0 in (1.9 m)

Diameter: 7.1 in (180.0 mm)

Span: 22.0 in (559.0 mm)

Systems.

Launchers: [Ref. 14], [Ref. 33]

A six missiles box launcher for the Seawolf GWS 25 system. A four missiles box launcher for the Lightweight Seawolf VM40 system.

The Royal Navy fitted with the Seawolf missile are:

1. 4 Type 22 with two six-box launchers [Ref. 14], [Ref. 33].
2. 5 Type 22 with single six-box launcher [Ref. 14], [Ref. 33].
3. 3 Invisible Class [Ref. 37: p. 89].
4. Type 23 [Ref. 37: p. 89].
5. Type 24 A [Ref. 37: p. 89].
6. Type 42s [Ref. 37: p. 89].
7. Type 44 [Ref. 37: p. 89].

The Seawolf missile's console: [Ref. 37: p. 89]

Guided Weapons System Mk 25 Mod 0 (GWS 25 Mod 0) and GWS 25 Mod 1

Minimum/Maximum Range: [Ref. 14]

max. 28 mi (45 km) for Mk 1
max. 36 mi (58 km) for Mk 2
slant range 15 mi (24 km) [Ref. 19: p. 189]

Minimum/Maximum Altitude: [Ref. 19]

500 - 50,000 ft (150 - 15,000 m)

Target Maneuverability:

no information available

Target Destructibility: [Ref. 14]

Single Shot Kill Prabability, Pkss = 0.92

Seaslug: Type 901

Tracking in X-band (10 GHz), λ = 0.03 m

Assume:

Antenna diameter, d = 2.44 m
Antenna area, A = 4.67 sq.m
Receiver bandwidth, B = 1 MHz
Noise figure, F = 4.90 dB = 3.09 (from fig 2.3)
$(S_o/N_o)_{min}$ = 14.7 dB = 29.51
From equation 2.16; $S_{min} = 3.65 \times 10^{-13}$ watts

Assume:

For an antenna efficiency, ρ = 0.85, A_e = 3.97 sq.m
For target cross section 1 sq.m, n = 30, and Ls = 20
Average power, P_t = 10 KW

From equation 2.18; R_{max} = 70 km

Fig. 5.3 shows the maximum radar range and the maximum and minimum missile range versus target altitude.

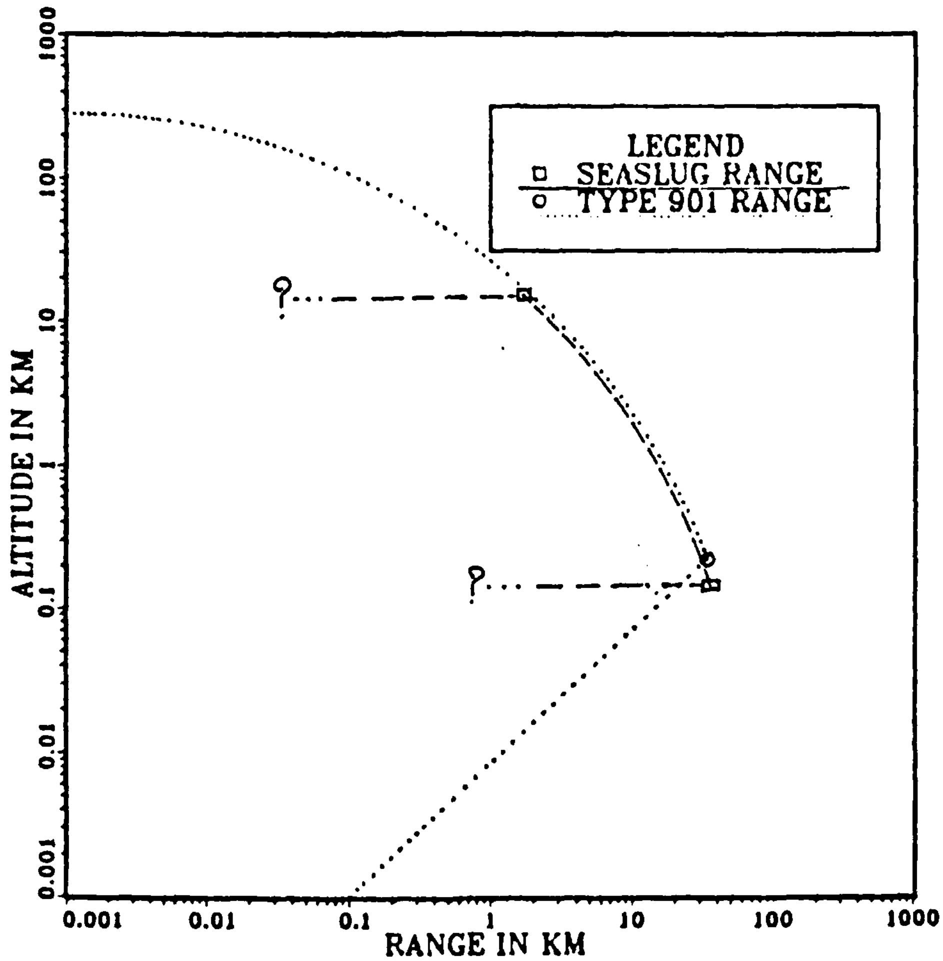

Figure 5.3 Comparison of Seaslug Missile and Type 901 Tracking Radar.

TABLE 5

Comparison of the Missile Specifications in the Royal Navy

Missile	Dimension			Propulsion	Guidance		Launch Weight	Warhead		Speed	Range		Intercept		Remarks
	L m	Dia mm	Span mm		Guidance	Navigation	(kg)	Weight kg	Type	Mach	Min m	Max m	Min m	Max m	
Seacat	1.48	191	650	Dual thrust solid motor	Radio comm.	CLOS	65	20.45	Continuous rod	750 ft/s.	500 500	5000 7000	2	10	sur-to-air sur-to-sur
Sea Dart/ Lightweight Sea Dart	4.40	420	960	Composite DB booster, kerosene liquid fuel ramjet	SARH	Prop. Nav.	549	-	Frag. with externally grooved casing	3.5	30000	50000	30	25000	
Seawolf/ Lightweight Seawolf	1.9	180	559	Tandem integral rocket motor	Radio comm.	CLOS	82	14	Blast Frag.	2.0	-	4630	-	600	
SLAM	1.4	76	274	Solid prop. rocket motor	Radio comm.	CLOS	11	2	Frag. with smooth frament casing	1.5	3000	-	-	2000	
Seaslug	5.99 6.13	409	1440	Solid prop. booster and sustainer	Beam riding	-	2000	135	-	1.8	-	45000 58000	150	15000	for Mk 1 for Mk 2

VI. ITALIAN NAVY

The surface-to-air missiles in the Italian Navy are:

1. ALBATROS ASPIDE Missile System.
2. STANDARD SM1-MR Missile.
3. STANDARD SM1-ER Missile.
4. NATO SEASPARROW Missile.

A. ALBATROS ASPIDE MISSILE SYSTEM

The Albatros missile system is to be considered as a part of the ship's air defence system that interfaces with be ship's gunfire control system. The system provides for the store, launching and guidance of the Aspide missiles. It is composed of a number of units, which may be grouped in three major items: [Ref. 42]

1. The Albatros missile system.

The Albatros missile system provides control for the firing of the Aspide missiles against the assigned target. The system interfaces with the Gun Fire Control System (GFCS) through the Missile Section Control Unit. This unit contains a computer and performs the supervision and control of operation of the complete system. The CW energy for target illumination and missile reference, is generated by the CW transmitter group and injected directly into the Gun Fire Control System waveguide assembly for radiation through the tracker antenna. Missile firing is controlled at the Weapon Control Console of the associated GFCS by means of a missile control panel. Initial orders to the launcher are sent during the acquisition phase, for moving the launcher in the stand-by condition to the present point direction. The maximum firing rate is one missile every 2.5 seconds.

2. The Albatros store and reload system.

The albatros store and reload system is based on a hydraulically operated 16-unit missile magazine (12 or 8 missile unit magazines are also available) which can be mounted below the launcher deck or on the same deck of the launcher.

3. The Aspide missile.

The Aspide missile is a multi-role, point defence, supersonic missile (Mach 2.0), powered by a single stage solid propellent rocket motor. Four movable wings, arranged in a 45 degree off center line pattern, are situated along the missile fuselage, for roll stabilization and steering control, while other four fixed fins, in line with the control surfaces, provide aerodynamic lift and stability. The type of guidance is the semi-active guidance with proportion navigation. The target is illuminated by the CW energy generated by the Albatros system illuminator. The Aspide missile seeker receives the target echo in its front receiver and the direct illuminator signal in the rear receiver.

1. <u>Physical Description</u>

Dimensions. [Ref. 42]

Length: 12.14 ft (3.7 m)

Diameter: 8.0 in (203.0 mm)

Span: 31.5 in (800.0 mm)

Systems.

Launchers: [Ref. 42]

A standard 8-cell missile launcher with a magazine capacity for 16, 12 or 8 missiles depending upon ship's spare availability.

The Italian Navy ships fitted with the Albatros Aspide missile are: [Ref. 19]

1. 1 Garibaldi Class (Giuseppe Garibaldi) with two 8-cell Albatros launcher with 16 Aspide ready reload and 56 more in reserve. [Ref. 31], [Ref. 43: p. 23]. Of these 32 are contained in two 16-round magazines.
2. 1 Animoso Ardimentoso in "Improved Audace" destroyers Class with one 8-cell Albatros launcher.
3. 8 Maestrale Class with one 8-cell Albatros launcher with 16-missile magazine below the deck just behind the launcher. [Ref. 44: p. 432]
4. 4 Lupo Class with one 8-cell launcher.[25]
5. 4 New construction corvettes with one 8-cell Albatros launcher.

The Albatros Aspide's console:

Albatros missile system consists of;

1. Missile guidance sub-section
2. Missile launching sub-section
3. Missile magazine
4. Aspide missile

The Albatros systems are controlled by the fire control system NA 30 A (or B) associated with fire control radars; i.e. RTN 30 etc.; the optical-electronic (optronic) sensor package comprising an infra-red

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[25]Aspide missile can be launched from NATO Sea Sparrow launcher.

thermal camera, a laser arrange finder and a daylight TV camera [Ref. 43: p. 23].

Types of radar required for the Albatros Aspide missile: [Ref. 14]

Surveillance radar.

Type: Type RAN-10S S-band combined search surveillance radar.

Tracking radar.

Type: RTN 12X CW illumination radar
RTN 30X I/J-band monopulse tracking radar

Description: The RTN 30X is a monopulse acquisition and tracking radar operating in the I/J-band. It has intercepted target up to 15 km [Ref. 7: p. 498] and is particularly optimised to counter the low and very low altitude threat in an environment characterized by rain, sea, and land clutter, and dense ECM (electronic countermeasures). The RTN-30X employs a coherent chain for RF generation and operates with frequency agility and simultaneous MTI processing. Independent search and acquisition patterns are automatically performed according to computer programs. After radar lock-on, the radar switches to automatic tracking in which regeneration is provided by the NA 30 fire control computer system.[26]

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[26]For Lupo, Maestrale, Garibaldi Class [Ref. 45: p. 271], [Ref. 46: p. 244].

Launch Weight. [Ref. 42]

484 lb (220 kg)

2. Propulsion

A single stage solid propellant rocket motor. [Ref. 42]

3. Warhead Section

Type of Warhead: [Ref. 42]

Preformed steel fragmentation

Weight of Warhead: [Ref. 47]

77 lb (35 kg)

Fuze System: [Ref. 14], [Ref. 42]

Active proximity sensor fuze

Damage Mechanism: [Ref. 42]

a large number of steel fragments and the blast wave

Explosive Type:

High Explosive (HE) warhead

4. Target Detecting, Tracking, and Missile Guidance

The Aspide missile is the standard ammunition for the Albatros system. Aspide is claimed to have capability against all anti-ship aircraft or missiles including those descending from above or skimming the waves. The type of guidance of the missile is of semi-active radar homing which

keeps the missile on a collision course following proportional navigation.

Operation of the systems begins when the incoming targets are detected by the RTN 30X monopulse tracking radar. The target information is then transfered to the NA 30 integrated weapon control system [Ref. 45: p. 271]. The system commands the RTN 12X CW illuminating radar to illuminate the target and launch the missile. The Aspide missile seeker receives the target echo in its front receiver and the direct illuminator signal from RTN 12X in the rear receiver. In processing the two signals, there results target doppler, which is used for automatic target range rate tracking.

If the target radiates a jamming signal to deny the target echo to the missile, the guidance system switches to the passive home-on-jam mode. In this mode, the missile derives the guidance information from the jamming signal emitted by the target, thus allowing it to successfully continue the intercept with the target. If the jamming transmitter is turned off, the missile switches back to the semi-active homing mode again.

Type of Guidance: [Ref. 7], [Ref. 14], [Ref. 42]

Semi-active radar homing (SARH)

Type of Navigation: [Ref. 42]

Proportional Navigation

5. Performance

Speed: [Ref. 42]

Mach 2.0

Minimum/Maximum Range: [Ref. 42]

very short ranges out to about 15 km

Minimum/Maximum Altitude: [Ref. 19], [Ref. 42]

50 - 16,000 ft (15 - 5,000 m)

Target Maneuverability:

more than 30-g

Target Destructibility: [Ref. 42]

Single Shot Kill Probability, Pkss = 0.8
Double Shot Kill Probability = 0.96
Three Shot Kill Probability = 0.992

Albatros vs RTN-30X

Tracking in I/J-band (15 GHz), λ = 0.02 m

Assume:

Antenna diameter, d = 1 m
Antenna Area, A = 0.79 sq.m
Receiver Bandwidth, B = 1 MHz
Noise Figure, F = 4.30 dB = 2.69 (from Fig. 2.3)
$(S_o/N_o)_{min}$ = 14.7 dB = 29.51
From equation 2.16; $S_{min} = 3.18 \times 10^{-13}$ watts

Assume:

For antenna efficiency = 0.85, A_e = 0.67 sq.m
For a target cross section 1 sq.m, n = 30, and
Ls = 20, P_t = 5 KW

From equation 2.18; R_{max} = 30 km

Fig. 6.1 shows the maximum radar range and the maximum and minimum missile range versus target altitude.

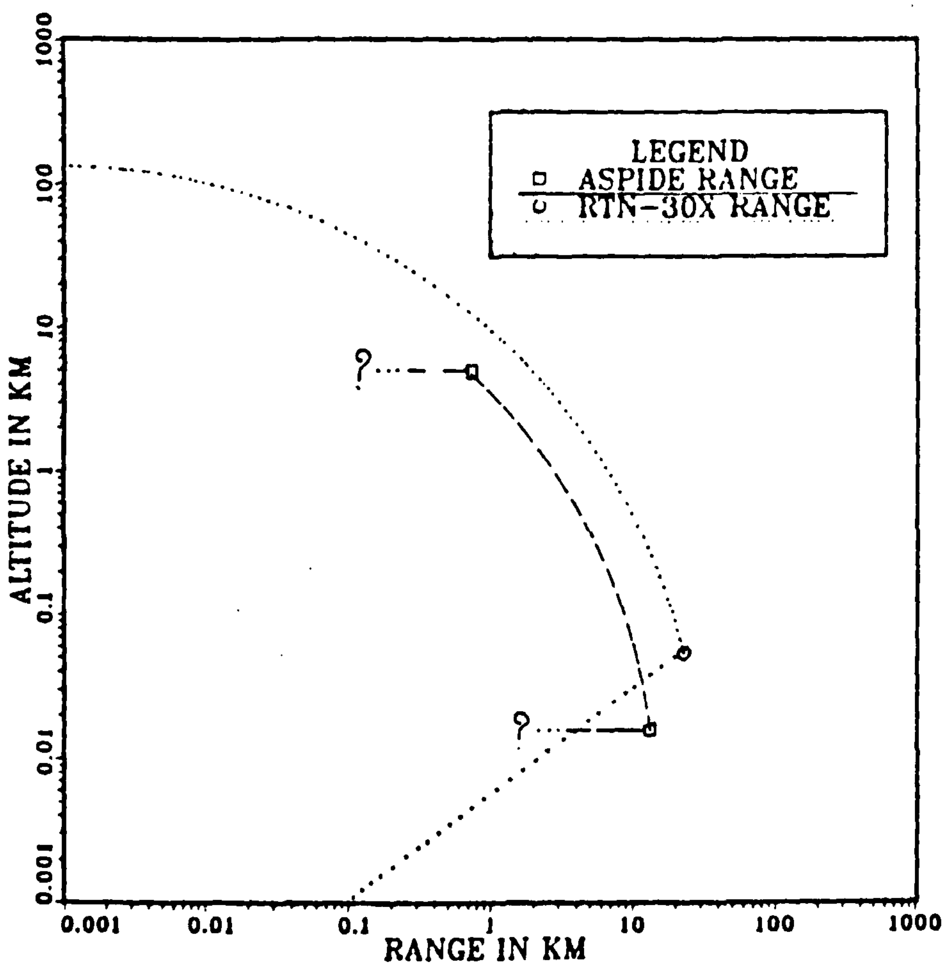

Figure 6.1 Comparison of Albatros Missile and RTN-30X Tracking Radar.

B. STANDARD SM1-MR

The Standard SM1-MR missile has the same specifications and missile guidance system on board The Italian Navy ships fitted as used in the US Navy. The Italian Navy ships fitted with the Standard SM1-MR missile are: [Ref. 11]

1. 2 Andrea Class with one single arm Mk 13 launcher with 36 SM1-MR missiles stored.

2. 2 Impavido Class with one single arm Mk 13 launcher with 36 SM1-MR missiles stored.

C. STANDARD SM1-ER

The Standard SM1-ER missile in the Italian Navy has the same specifications and missile guidance system as used in the US Navy. The Italian Navy ships fitted with the Standard SM1-ER missile are: [Ref. 11]

1. 1 Garibaldi Class (Vittorio Veneto) with one twin (dual) arm Mk 10 launcher with 40 SM1-ER missiles stored.
2. 2 Andrea Doria Class with one twin (dual) arm Mk 10 launcher with 32 SM1-ER missiles stored.

D. NATO SEA SPARROW

The NATO Sea Sparrow used by the Italian Navy has the same specifications and missile guidance control as used in the US Navy. The Italian Navy ships fitted with the NATO Sea Sparrow missile is: [Ref. 11]

1. 4 Lupo Class with one 8-cell launcher.[27]

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[27] NATO Sea Sparrow modified to also fire Aspide missiles.

TABLE 6

Comparison of the Missile Specifications in the Italian Navy

Missile	Dimension			Propulsion	Guidance		Launch Weight	Warhead		Speed	Range		Intercept		Remarks
	L m	Dia mm	Span mm		Guidance	Navigation	(kg)	Weight kg	Type	Mach	Min m	Max m	Min m	Max m	
Aspide	3.7	203	800	Solid prop. rocket motor	SARH	Prop. Nav.	220	35	Preformed frag.	2.0	-	15000	15	5000	
SM1-MR	4.47	343	914	Solid prop. motor Mk56 Mod0	SARH	-	581	125	Fragmentation	2.5	-	30600	18	24400	
SM1-ER	7.98	343	914	1/Mk12 booster, 1/Mk30 sustainer	SARH	-	1344	-	Fragmentation	2.5	-	56300	15	24000	
NATO Sea Sparrow	3.66	203	1020	1/Mk56 Mod2 solid propellant rocket	SARH	Lead Angle	227	41	Continuous rod	2.5	22000	25000	5	5000	

VII. ISRAELI NAVY

The surface-to-air missile in the Israeli Navy is:

1. BARAK Missile.

A. BARAK

Barak is a ship point defence system designed to have an effective range of about 10 km against sea-skimming missiles, aircraft, and other anti-ship threats. Barak is capable of multiple target engagements under all weather conditions. The missile weighs about 90 kg with a blast fragmentation warhead and semi-active radar homing.

The system is comprised of three main units: a deck launcher containing eight Barak missiles on which is mounted an autonomous radar, a fire control unit which is mounted below deck, and a processing unit. The radar on the launcher unit, in addition to pointing with the launcher, has its own rapid scanning capacity, such as EL/M-2221, a dual-band radar with a single antenna providing both mono-pulse tracking and target illuminating facilities. The missile configuration incorporates cruciform wings and tail control surfaces. The Barak launcher can engage targets within a 360 degree azimuth and between -25 degree and + 85 degree elevation.

Barak 1, is the latest version, uses the vertical launch mode. The vertical launch units (VLUs) can contain up to eight missiles with a magazine capacity for a total of 32 missiles.

TABLE 8

Canadian Sea Sparrow Specifications in the Canadian Navy

Missile	Dimension			Propulsion	Guidance		Launch Weight	Warhead		Speed	Range		Intercept		Remarks
	L m	Dia mm	Span mm		Guidance	Navigation	(kg)	Weight kg	Type	Mach	Min m	Max m	Min m	Max m	
Canadian Sea Sparrow	3.66	203	1020	Rocketdyne free-standing solid motor with Plexa-dyne prop.	SARH	-	200	30	Continuous rod	3.7	8000	10000	-	-	

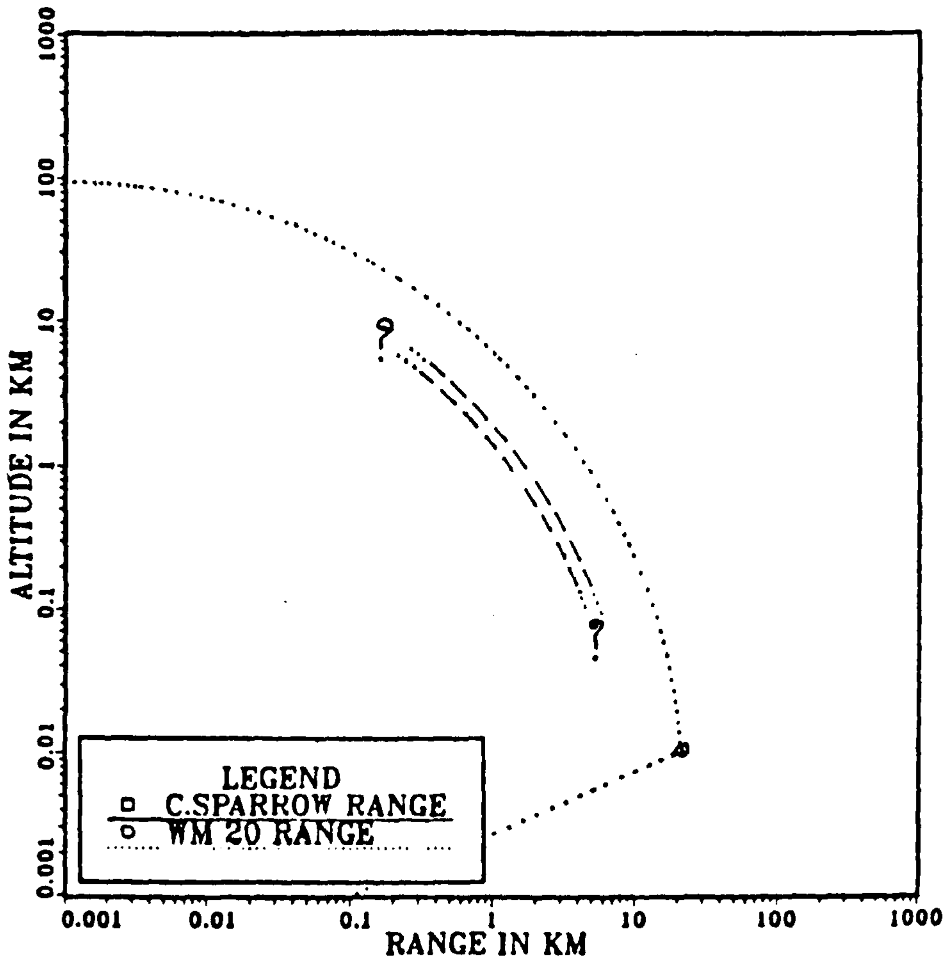

Figure 8.1 Comparison of Canadian Sea Sparrow Missile and WM20 Tracking Radar.

Minimum/Maximum Range: [Ref. 19]

26,000 - 33,000 ft (8,000 - 10,000 m)

Minimum/Maximum Altitude:

no information available

Target Maneuverability:

no information available

Target Destructibility:

no information available

Canadian Sea Sparrow vs WM20

Tracking in I/J-band (15 GHz), $\lambda = 0.02$ m

Assume:

Antenna diameter, d = 1 m

Antenna area, A = 0.79 sq.m

Receiver bandwidth, B = 1 MHz

Noise figure, F = 5.38 dB = 3.45 (from fig. 2.3)

$(S_o/N_o)_{min}$ = 14.7 dB = 29.51

Antenna efficiency, ρ = 0.85, A_e = 0.67 sq.m

A target cross section 1 sq.m, n = 30, and

Ls = 20

Average power, P_t = 5.0 KW

From equation 2.16; $S_{min} = 3.65 \times 10^{-13}$ watts

From equation 2.18; R_{max} = 22 km

Fig. 8.1 shows the maximum radar range and the maximum and minimum missile range versus target altitude.

4. Target Detecting, Tracking, and Missile Guidance

The engagement event begins when the ship's surveillance radar detects all the approaching targets and, simultaneously, the IFF system identifies those which are potentially hostile. The target velocity, bearing, and, probably, size are measured. These data are passed on to the computer-controlled tracker, Signaal WM 20, which commands the launcher to pick up the missile, slews the tracker to the correct bearing, and commences a search, leading to target acquisition. Once the tracker locks on to the target, it starts tracking with the WM 20 tracker radar continually supplying an update of information until the end of engagement. The twin (dual) arm launcher is instructed by the data handling computer to point at the target and the system is ready to fire after tracker allocation.

During semi-active homing flight, the guidance and control section of missile tracks a target using both the target reflected illuminating signal and the tail-received reference signal from the signaal WM20 radar and directs and stabilizes the missile on its course to the target. The fuze initiates the warhead detonation at the proper point of intercept.

Type of Guidance: [Ref. 14]

Semi-active radar homing (SARH)

Type of Navigation:

no information available

5. Performance

Speed: [Ref. 14: p. 229]

Mach 3.7

prediction. Search radar data are presented on a PPI, air tracking data on an A-scope, and surface tracking and spotting data on a B-scope. Both antennas are fed from a common I/J-band transmitter.

Launch Weight. [Ref. 14]

4,400 lb (200 kg)

2. Propulsion

Rocketdyne free-standing solid motor with Flexadyne propellant (Mk 38)

3. Warhead Section

Type of Warhead: [Ref. 14: p. 229]

Continuous stainless steel rod

Weight of Warhead: [Ref. 14]

66 lb (30 kg)

Fuze System:

Direct Action (DA) and proximity fuze

Damage Mechanism: [Ref. 14: p. 229]

Stainless steel rods which shatters into 2600 fragments.

Explosive Type:

High Explosive (HE) warhead

4. A control and interface group. Information from radar and other input data are processed to determine target status and future position of targets. Then information generated is passed to the ship's tactical data system, to the GMFCS as the target designations, and to the GMLS and missiles as pre-launch and steering commands.

Types of radar required for the Canadian Sea Sparrow missile: [Ref. 11]

Surveillance radar.

Type: air search radar[32]
surface search radar[33]

Tracking radar.

Type: Signaal WM20 series fire control radar

Description: The radar can track air and surface targets simultaneously with the tracking antenna in the upper position and the search antenna below. It is equipped with mono-pulse tracking, track-while-scan facilities, MTI search, pulse-doppler tracking, extensive ECCM facilities, a missile guidance capability, and a digital computer for system control tracking and weapon

[32]For example, SPS-49 air search radar for Halifax Class.

[33]For example, LM Ericsscn Sea Giraffe 150HC naval search radar.

2. 6 Halifax (Canadian Patrol Frigate, CPF) Class[31] with sixteen vertical Canadian Sea Sparrow launchers.

The Canadian Sea Sparrow's console: [Ref. 7: p. 96]

The system comprises four sub-systems:

1. The AIM-7E2 Sparrow missile. The missiles can be fired singly or in rapid succession, automatic pre-launch commands being supplied to the missile electrically.
2. A guided missile launching system (GMLS). It is carried on a four-missile support pylon on an extensible cantilever beam. The launcher head rotates automatically about horizontal and vertical axes under the control of the GMLS. The dual launcher has a magazine capacity for 16 missiles.
3. A Signaal M22/6 gun/missile fire control system (GMFCS). The M22/6 GMFCS provides simultaneously early warning, air target tracking, and surface target tracking and can control both the missiles and the ship's gun in simultaneous operation against air and surface targets.

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[31]Canada requires twenty, only six are on order so far, with the first HMCS Halifax, to be laid in December 1984 and for deliver in 1989. Two ships will be delivered in 1990 and two in 1991 and the sixth in April 1992.

VIII. CANADIAN NAVY

The surface-to-air missiles in the Canadian Navy is:

1. CANADIAN SEA SPARROW Missile.

A. CANADIAN SEA SPARROW

The Canadian Sea Sparrow missile system is intended for use in both surface-to-air and surface-to-surface engagements.

1. Physical Description

Dimensions. [Ref. 19: p. 43]

Length: 144.0 in (3.66 m)

Diameter: 8.0 in (203.0 mm)

Span: 40.0 in (1020.0 mm)

Systems.

Launchers: [Ref. 7: p. 96], [Ref. 14: p. 182]

A twin (dual) arm launcher

The Canadian Navy ships fitted with the Canadian Sea Sparrow missile are: [Ref. 7], [Ref. 11], [Ref. 14]

1. 4 Iroquois DD 280 Class destroyers with two twin (dual) arm launchers (4 quad launchers) with a magazine capacity for 16 missiles, total 32 missiles stored.

TABLE 7

Barak Missile Specifications in the Israeli Navy

Missile	Dimension			Propulsion	Guidance		Launch Weight (kg)	Warhead		Speed	Range		Intercept		Remarks
	L m	Dia mm	Span mm		Guid-dance	Navig ation		Weight kg	Type	Mach	Min m	Max m	Min m	Max m	
Barak	2.4	150	-	Solid prop. rocket motor	SARH	-	90	-	Blast frag	-	-	10000	-	-	

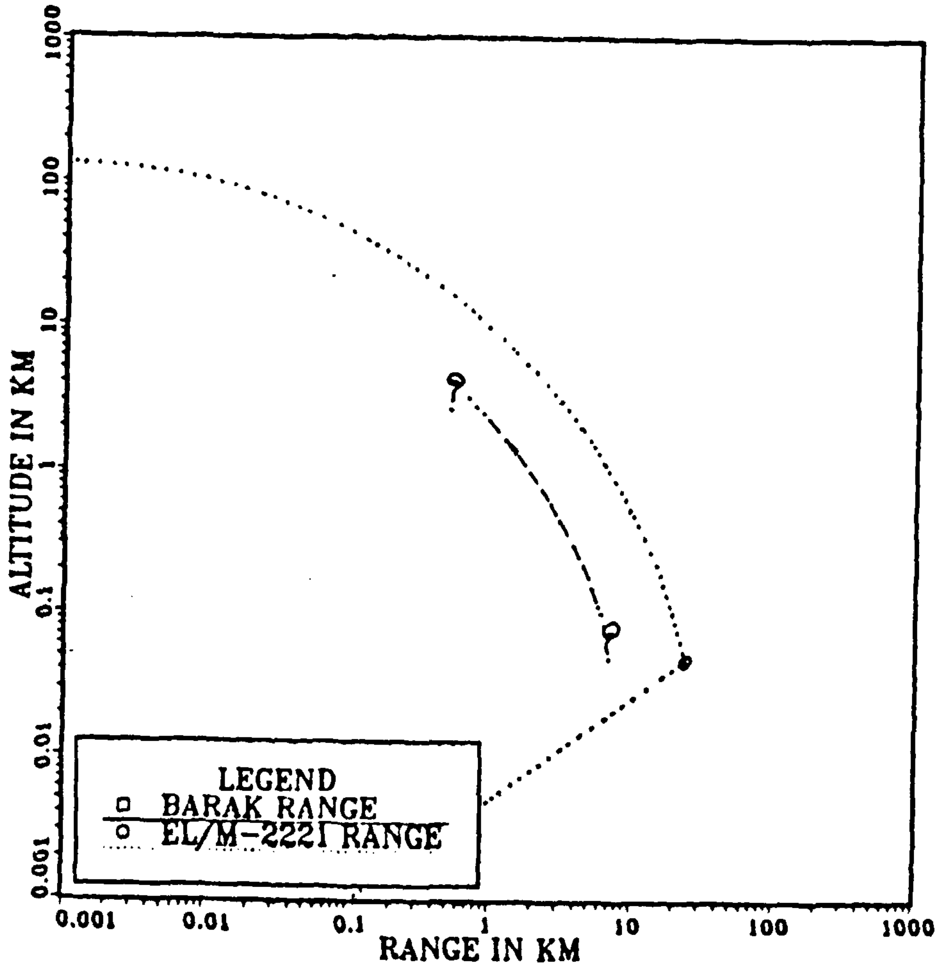

Figure 7.1 Comparison of Barak Missile Range and EL/M-2221 Tracking Radar.

Assume:

Receiver bandwidth, B = 1 MHz

Noise figure, F = 4.3 dB = 2.69 (from fig. 2.3)

$(S_o/N_o)_{min}$ = 14.7 dB = 29.51

From equation 2.16; $S_{min} = 3.18 \times 10^{-13}$ watts

Assume:

For an antenna efficiency, ρ = 0.85, A_e = 0.67 sq. m

For a target cross section 1 sq. m, n = 30, Ls = 20

Average power, P_t = 5 KW

From equation 2.18; R_{max} = 30 km

Fig. 7.1 shows the maximum radar range and the maximum and minimum missile range versus target altitude.

flight, the target and missile ranges, elevations, and bearings are continuously fed to a ship's computer system. The Barak missile seeker receives the target echo in its front receiver and the direct illuminator signal from the illuminator radar.

Type of Guidance: [Ref. 7: p. 133]

semi-active radar homing (SARH)

Type of Navigation:

no information available

5. Performance

Speed:

supersonic

Minimum/Maximum Range: [Ref. 7: p. 133]

max. 10 km

Minimum/Maximum Altitude:

no information available

Target Maneuverability:

no information available

Target Destructibility:

no information available

Barak vs EL/M-2221

Tracking in I/J-band (15 GHz), $\lambda = 0.02$ m
Antenna diameter, $d = 1.0$ m
Antenna area, $A = 0.79$ sq.m

Launch Weight. [Ref. 7: p. 133]

198 lb (90 kg)

2. Propulsion

Solid propellant rocket motor.

3. Warhead Section

Type of Warhead: [Ref. 7: p. 133]

Blast fragmentation

Weight of Warhead:

no information available

Fuze System: [Ref. 7: p. 133]

Contact and proximity fuze

Damage Mechanism: [Ref. 5]

Blast wave produced by the detonation of the high explosive (HE) charge

Explosive Type:

High Explosive (HE) warhead

4. Target Detecting, Tracking, and Missile Guidance

The operation of the system begins when the incoming targets are designated to the fire control system, the EL/M 2221 by the air search radar, presumably the EL/M-2207 naval search radar. The EL/M-2221 tracks as well as illuminates the target. When the target comes into the range of the missile, the missile is launched. During semi-active homing

1. Physical Description

Dimensions [Ref. 7: p. 133]

Length: 7.87 ft (2.40 m)

Diameter: 38.1 in (150 mm)

Systems.

Launchers: [Ref. 7: p. 133]

A standard eight missile launcher.

The Barak's console: [Ref. 7: p. 133]

The system consists of 3 main units:

1. A deck launcher containing eight Barak missiles.
2. A fire control console.
3. A processing unit.

Each Barak system has a magazine capacity for total 32 missiles.

Type of radar required for the Barak's missile:

Surveillance radar.

Type: EL/M-2207 F-band naval search radar[28]

Tracking radar.[29]

Type: EL/M-2221 J-band naval fire control radar[30]

---

[28]As the example in the Israeli Navy. It is not required for the Barak missile.

[29]The Barak dual-band radar with single antenna provides both monopulse tracking and target illumination.

[30]As the example in the Israeli Navy. It is not required for the Barak missile.

IX. SOVIET NAVY

The surface-to-air missiles in the Soviet Navy[34] are:

1. SA-N-1 Goa Missile.
2. SA-N-2 Guideline Missile.
3. SA-N-3 Goblet Missile.
4. SA-N-4 Missile.
5. SA-N-5 Missile.
6. SA-N-6 Missile.
7. SA-N-7 Missile.

A. SA-N-1

This was the first surface-to-air missile to be widely fitted in Soviet warships and is considered effective at low to medium altitudes (about 300 - 15,000 meters) and in the surface-to-surface mode. However, this section will only present surface-to-air version. The missile is fired from a single twin (dual) arm launcher with a magazine capacity for 20 missiles in destroyers and one or two launchers in cruisers. The missile can be locked at 90 degree elevation from a below-deck magazine. The Goa missile is cylindrical and slim with relatively large-cruciformed fixed wing in the rear and small cropped-delta control surfaces on the tapered nose. The booster is short, but large in diameter (700 mm. approx.), and is furnished with rectangular fins indexed in line with the other control surfaces. Some versions of the missiles have trailing-edge control by small tail fins between the booster and the second stage wings. The SA-N-1 is derived from the land-based SA-3 system, hence its name

[34]The current Soviet Navy has fitted more SAMs than given in this chapter.

Goa. Maximum speed is approximately Mach 2.0 [Ref. 48: p. 358].

1. <u>Physical Description</u>

Dimensions. [Ref. 7], [Ref. 19]

Length: 19.4 ft (5.9 m)

Diameter: 27.6 in (700.0 mm) booster

18.1 in (460.0 mm) missile

Span: 48.0 in (1.22 m)

Systems.

Launchers: [Ref. 48: p. 358]

A twin (dual) arm launcher and two twin (dual) arm launchers.

The Soviet Navy ships fitted with the SA-N-1 missile are: [Ref. 11]

1. 4 Kynda Class with one twin (dual) arm launcher with a magazine capacity for 20 missiles.
2. 4 Kresta-I Class with two twin (dual) arm launchers with a magazine capacity for 20 missiles, total 40 missiles stored.
3. 11 Kashin Class with two twin (dual) arm launchers with a magazine capacity for 20 missiles, total 40 missiles stored.
4. 6 Modified Kashin Class with two twin (dual) arm launchers with a magazine capacity for 20 missiles, total 40 missiles stored.

5. 8 Kanin Class with one twin (dual) arm launcher with a magazine capacity for 20 missiles.
6. 8 Kotlin Class with one twin (dual) arm launcher with a magazine capacity for 20 missiles.

The SA-N-1 Goa's console:

The launcher is mounted on top of the missile magazine and is reloaded vertically through hatches. The SA-N-1 missile receives command guidance from the Peel Group fire control radar.

Types of radar required for the SA-N-1 Goa missile: [Ref. 11], [Ref. 19]

Surveillance radar.

Type: Head Net A or C air surveillance radar

Tracking radar.

Type: Peel Group fire control radar

Description: This group comprises four distinct radars on a common mounting with elliptical paraboloid shape and solid reflectors. Within the group are an H/I-band monopulse tracking radar for high-altitude targets and an E-band guidance radar for low altitude targets. The maximum range is 30 - 40 miles (55 - 75 km) [Ref. 7: p. 512]. Two large and two small antennas (in I-band) in each group are mounted in horizontal and vertical directions. The larger elements of the group

are presumably for long range, or coarse tracking, with the small radar for tracking at closer range. [Ref. 49: p. 263]

Launch Weight. [Ref. 14: p. 157]

882 lb (400 kg)

2. Propulsion

Solid-fuel rocket with tandem solid-fuel booster [Ref. 17: p. 54].

Launch: Solid propellant booster

Cruise: Solid propellant sustainer

3. Warhead Section

Type of Warhead: [Ref. 48]

Conventional warhead

Weight of Warhead: [Ref. 14: p. 157], [Ref. 17: p. 54], [Ref. 19: p. 527]

132 lb (60 kg)

Fuze System: [Ref. 50]

Active doppler radar fuze

Damage Mechanism:

no information available

Explosive Type:

High Explosive (HE) warhead

4. Target Detecting, Tracking, and Missile Guidance

The SA-N-1 missile uses a combination of midcourse command guidance and terminal semi-active radar homing guidance system [Ref. 7], [Ref. 27]. The operation of the system begins when target designation is provided by the Head Net A or C air surveillance radar and these inputs are processed to determine the possibility of engaging the target. Commands are then generated for the launcher by the fire control system. The tracking radar, one of two dishes of Peel Group, detects targets automatically and commands the Goa missile to fly into engagement range.

Goa is command-guided during the midcourse by the illuminated signal from the director tracking target radar (the second dish of Peel Group). During the midcourse guidance phase, the commands which control the missile come from the Weapon Computer Control System[35] which determines the correct flight path of the missile and compares this computed flight path with the predicted flight path of the missile based on current tracking information. It determines the correct signals required to move the missile control surfaces to change the current flight to the new one until it reaches the terminal phase.

The terminal guidance phase is semi-active radar homing during which the missile obtains its doppler information by comparing the reflected beam from the target with a beam transmitted directly by the Peel Group illuminator radar. At a distance of 300 meters (990 ft) from the target, the active doppler radar fuze is activated [Ref. 50].

---

[35]No information is available for this system

Type of Guidance: [Ref. 50]

Radio command and probably semi-active radar homing terminal guidance

Type of Navigation:

no information available

5. Performance

Speed: [Ref. 27], [Ref. 48: p. 358]

Mach 2.0

Minimum/Maximum Range:

min. 2,700 m. [Ref. 50]
max. 30 - 35 km. [Ref. 17: p. 54]
slant 28.8 km. [Ref. 27: p. 465]

Minimum/Maximum Altitude: [Ref. 19: p. 527]

1,000 - 50,000 ft (300 - 15,000 m)

Target Maneuverability:

no information available

Target Destructibility:

no information available

SA-N-1 vs Peel Group
Tracking in H/I-band

R_{max} = 75 km [Ref. 7: p. 512]

Fig. 9.1 shows the maximum radar range and the maximum and minimum missile range versus target altitude.

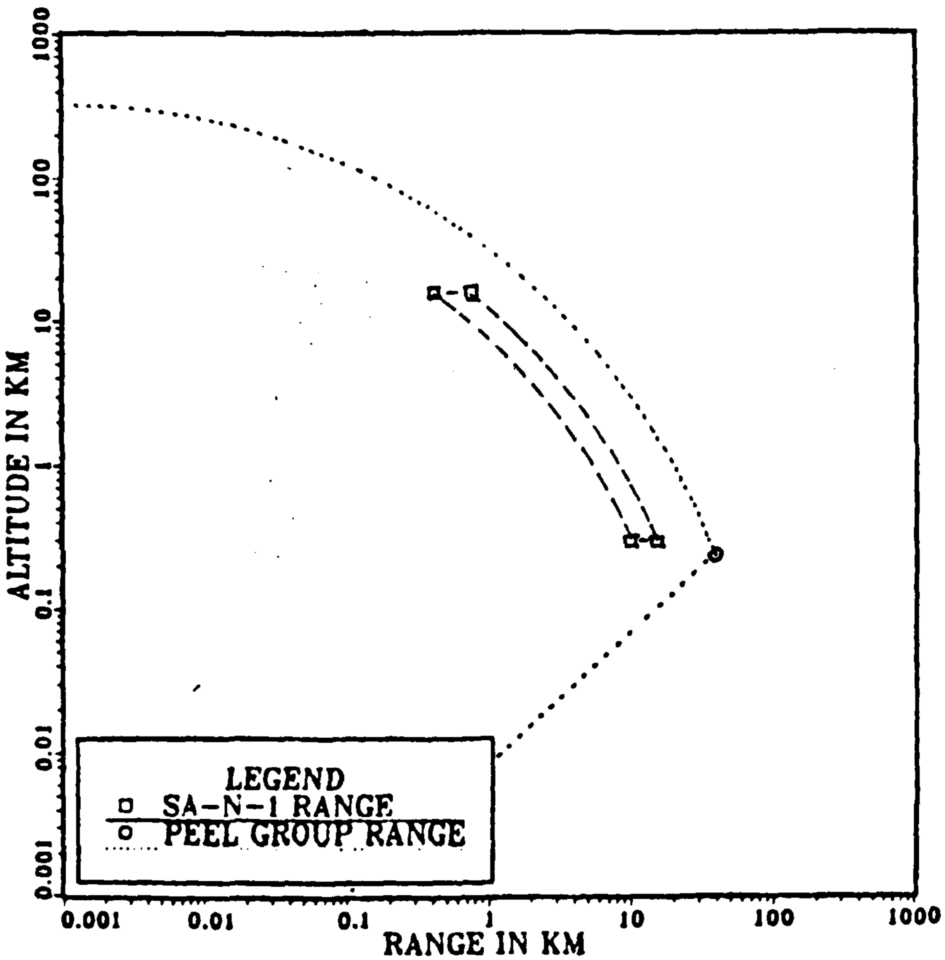

Figure 9.1 Comparison of SA-N-1 Missile and Peel Group Fire Control Radar.

B. SA-N-2

The SA-N-2, whose NATO code-name is "Guideline", was adapted from the land-based SA-2 system and is considered effective at low to medium altitude [Ref. 48]. It is a radio command guidance missile with a 288 lb (130 kg) fragmentation warhead with internal grooved casing [Ref. 14] and proximity fuze. Maximum speed is approximately Mach 3.5.

The Fan Song E fire control radar guides the missile in the shipborne surface-to-air version which is similar to land-based version.

1. <u>Physical Description</u>

Dimensions [Ref. 15]

Length: 35.5 ft (10.7 m)

diameter: 26.0 in (660.4 mm)

Span: 86.6 in (2.2 m) booster

66.9 in (1.7 m) missile

Systems.

Launchers: [Ref. 19]

A twin (dual) arm launcher

The Soviet Navy ship fitted with the SA-N-2 missile is; [Ref. 19: p. 527], [Ref. 48: p. 358]

Dzerzhinskiy guided-missile cruises with one twin (dual) arm launcher at aft.

The SA-N-2 missile's console:

A twin (dual) arm launcher which has control command from the Fan Song E fire control system.

Types of radar required for the SA-N-2 Guideline missile: [Ref. 11]

Surveillance radar.

Type: Big Net air search radar
Low Sieve surface search radar

Tracking radar.

Type: Fan Song E fire control radar

Description: Fan Song E operates in the G/H-band range of frequency. The antenna arrays consist of horizontal and vertical scan Lewis antenna and three circular parabolic dishes. Two of the latter are for lobe on receive only (LORO) ECCM, and the third dish is for command guidance purpose. The beams are about 7.5 degree wide in the fan and about 1.5 degree wide in the scanning direction. Carrier frequencies are 4910 to 4990 MHz and 5010 to 5090 MHz and peak power about 1.5 MW.

Launch Weight. [Ref. 14]

5,070 lb (2,300 kg)

2. Propulsion

Liquid propellant sustainer, burning nitric acid and hydrocarbon propellants; solid propellant booster. [Ref. 51: p. 93]

Launch: A solid propellant booster

Cruise: A liquid (nitric acid/hydrocarbon) sustainer

3. Warhead Section

Type of Warhead [Ref. 14], [Ref. 16]

Fragmentation with internally grooved casing

Weight of Warhead: [Ref. 14], [Ref. 51: p. 93]

288 lb (130 kg)

Fuze System: [Ref. 14]

Proximity fuze

Damage Mechanism:

a large number of fragments

Explosive Type:

High Explosive (HE) warhead

4. Target Detecting, Tracking, and Missile Guidance

The SA-N-2 has a radio command guidance system. The engagement event begins when the ship's surveillance radar, the Big Net air search radar or Low Sieve surface search radar, detects all the approaching targets and then measures the incoming target velocity, bearing, and probably size. These data from the search radar are passed on to the computer-controlled tracker, the Fan Song E which commands the launcher to pick up the missile, slew the tracker to the correct bearing and commence a search, leading to target acquisition and lock on to the target location. The twin (dual) arm launcher is instructed by the data handling computer to point at the target and the system is ready to fire after tracker allocation.

After the SA-N-2 is launched, the Fan Song E fire control radar tracks its target and the missile. During flight, the fire control system determines the correct flight path of the missile and compares this computed flight path with the predicted flight path of the missile based on current tracking information and determines the correct

signals required to move the missile control surfaces to change the current flight path to the new one.

Type of Guidance: [Ref. 15]

Radio command guidance

Type of Navigation:

no information available

5. Performance

Speed: [Ref. 51: p. 93]

Mach 3.5

Minimum/Maximum Range:

slant 40,000 m. [Ref. 19], [Ref. 27: p. 465]
max. 30 mi (48,000 m) [Ref. 6: p. 186]

Minimum/Maximum Altitude: [Ref. 19], [Ref. 27: p. 465]

100 - 80,000 ft (30 - 24,400 m)

Target Maneuverability:

no information available

Target Destructibility:

no information available

SA-N-2 vs Fan Song E

Tracking in G/H-band (6 GHz), $\lambda = 0.05$ m
Peak power = 1.5 MW
Average power = 1.5 KW

Assume:

Antenna diameter, d = 2.44 m
Antenna area, A = 4.67 sq.m

Receiver bandwidth, B = 1 MHz

Noise figure, F = 4.63 dB = 2.9 (from fig. 2.3)

$(S_o/N_o)_{min}$ = 14.7 dB = 29.51

From equation 2.16; $S_{min} = 3.42 \times 10^{-13}$ watts

Assume:

For an antenna efficiency, ρ = 0.85, A_e = 3.97 sq.m

For a target cross section 1 sq.m, n = 30, and Ls = 20

From equation 2.18; R_{max} = 72 km

Fig. 9.2 shows the maximum radar range and the maximum and minimum missile range versus target altitude.

C. SA-N-3

The SA-N-3 missile system uses the Goblet missile. The SA-N-3 is considered effective at low to medium altitude missile with improved capabilities over the SA-N-1 Goa and in the surface-to-surface mode. Maximum speed is approximately Mach 3.0. It is employed with the Head Light fire control radar.

1. Physical Description

Dimensions. [Ref. 24: p. 144], [Ref. 48: p. 358]

Length: 20.0 ft 4 in (6.20 m)

Diameter: 13.2 in (335.0 mm)

Span: 5.0 ft (1.5 m)

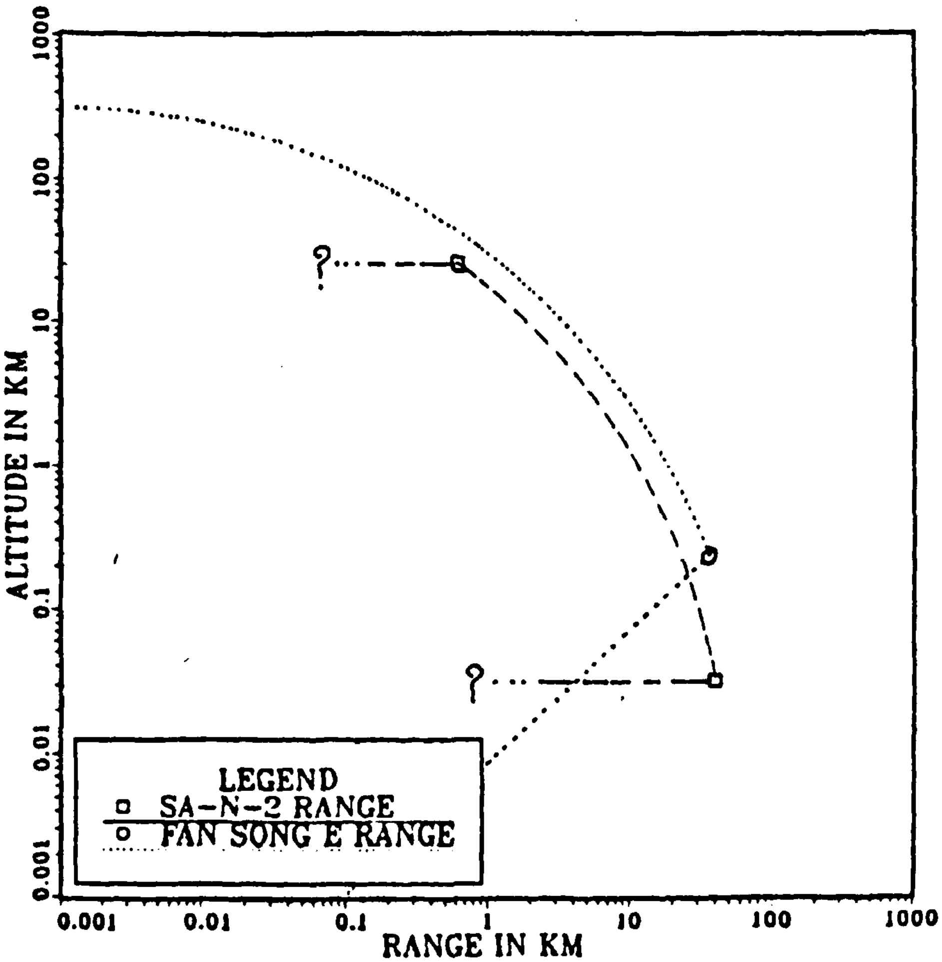

Figure 9.2 Comparison of SA-N-2 Missile and Fan Song E Fire Control Radar.

Systems.

Launchers:

A twin (dual) arm launcher

The Soviet Navy ships fitted with the SA-N-3 Goblet missile are: [Ref. 7], [Ref. 19], [Ref. 33]

1. 2 Moskva Class with two twin (dual) arm launchers with a magazine capacity for 20 missiles, total 40 missiles stored.
2. 10 Kresta II Class with two twin (dual) arm launchers with a magazine capacity for 20 missiles, total 40 missiles stored.
3. 7 Kara Class with two twin (dual) arm launchers with a magazine capacity for 20 missiles, total 40 missiles stored.
4. 3 Kiev Class with two twin (dual) arm launcher with a magazine capacity for 20 missiles, total 40 missiles stored.

The SA-N-3 missile's console:

A twin (dual) arm launcher with 2 SA-N-3 Goblet ready to fire and a rapid reloaded magazine capacity for 20 missiles.

Types of radar required for the SA-N-3 Goblet missile: [Ref. 7]

Surveillance radar.

Type: Top Sail 3-D air search radar
Head Net C height finding radar

Tracking radar.

Type: Head Light Group fire control radar

Description: Head Light Group is a fire control

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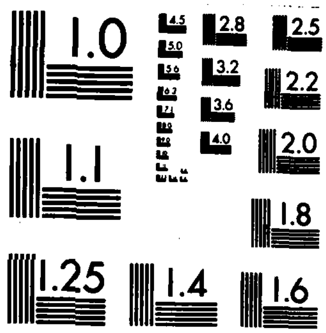

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

consisting of 4 radar groups with 2 identical pairs of equipment combined on a common mounting, one large and one small per pair. Dish diameters range from about 1.8 to 4.0 meters, with controls and electronics for each of the antenna behind. There is a fifth, small dish, possibly for the purpose of completing a command link or IFF function. Operating frequencies are in G-band for acquisition and H/I-band for tracking.

Launch Weight. [Ref. 14]

1,213 lb (550 kg)

2. Propulsion

Solid propellant booster. After burnout, its empty casing becomes a ramjet combustion chamber for ram air mixed with exhaust from a solid propellant gas generator. Ramjet with solid-fuel booster [Ref. 48: p. 358].

3. Warhead Section

Type of Warhead: [Ref. 6: p. 174], [Ref. 52]

Fragmentation warhead

Weight of Warhead: [Ref. 6: p. 174], [Ref. 14]

176 lb (80 kg)

Fuze System: [Ref. 24], [Ref. 52]

Passive proximity fuze

Damage Mechanism:

a large number of fragments

Explosive Type: [Ref. 24: p. 144]

High Explosive (HE) warhead with weight approximately 40 kg

4. Target Detecting, Tracking, and Missile Guidance

The SA-N-3 uses a combination of midcourse command guidance and terminal semi-active radar homing guidance system. The engagement event begins when the ship's surveillance radar detects all the approaching targets and then measures the incoming target velocity, bearing, and probably size. The IFF system will identify those which are potentially hostile. These data are passed on to the computer-controlled tracker, the Head Light Group, which commands the launcher to pick up the missile, slews the tracker radar to the correct bearing and commences a search, leading to target acquisition and lock on to the target. The twin (dual) arm launcher is instructed by the data handling computer to point at the target and the system is ready to fire after tracker allocation.

The SA-N-3 is command guided during the midcourse by a signal from the missile control radar. During this phase, the command which controls the missile comes from the Weapon Computer Control system. The terminal homing phase is semi-active radar homing during which the missile obtains its doppler information by comparing the reflected signal from the target with the signal transmitted directly by the Head Light Group illuminator radar. When the missile reaches the target, the passive proximity fuze causes detonation of the 80 kg fragmentation warhead.

Type of Guidance: [Ref. 5], [Ref. 24], [Ref. 52]

Semi-active radar homing (SARH)

Type of Navigation: [Ref. 14]

Command to line-of-sight (CLOS)

5. <u>Performance</u>

Speed: [Ref. 10: p. 195]

Mach 3.0

Minimum/Maximum Range: [Ref. 6: p. 174]

2.5 - 37 mi (4 - 59 km)

Minimum/Maximum Altitude: [Ref. 7], [Ref. 19: p. 527]

500 - 80,000 ft (150 - 25,000 m)

Target Maneuverability:

no information available

Target Destructibility:

no information available

SA N-3 vs Head Light Group

Tracking in H/I-band (8 GHz), $\lambda = 0.0375$ m
Antenna diameter, d = 2.44 m
Antenna area, A = 4.67 sq.m

Assume:

Average power, $P_t = 1.5$ KW
Receiver bandwidth, B = 1 MHz
Noise figure, F = 4.78 dB = 3.0 (from fig. 2.3)
$(S_o/N_o)_{min} = 14.7$ dB = 29.51
From equation 2.16; $S_{min} = 3.54 \times 10^{-13}$ watts

Assume:

For an antenna efficiency, $\rho = 0.85$, $A_e = 3.97$ sq.m

For a target cross section 1 sq.m, n = 30, and Ls = 20

From equation 2.18; $R_{max} = 83$ km

Fig. 9.3 shows the maximum radar range and the maximum and minimum missile range versus target altitude.

D. SA-N-4

The SA-N-4 is a point defence of large as well as small combat ships at a slant range of out to 1,200 m [Ref. 53: p. 187]. The SA-N-4 uses the Pop Group missile control radar which is similar to the radar associated with the land-based SA-8 Gecko surface-to-air missile. The missile is radio-command guided, with an impact and proximity fuze and a 40 - 50 kg conventional warhead [Ref. 24: p. 122].

1. Physical Description

Dimensions. [Ref. 48: p. 359]

Length: 10.20 ft (3.2 m)

Diameter: 8.25 in (210.0 mm)

Span: 25.2 in (640.0 mm)

Systems.

Launchers:

A twin (dual) arm launcher.

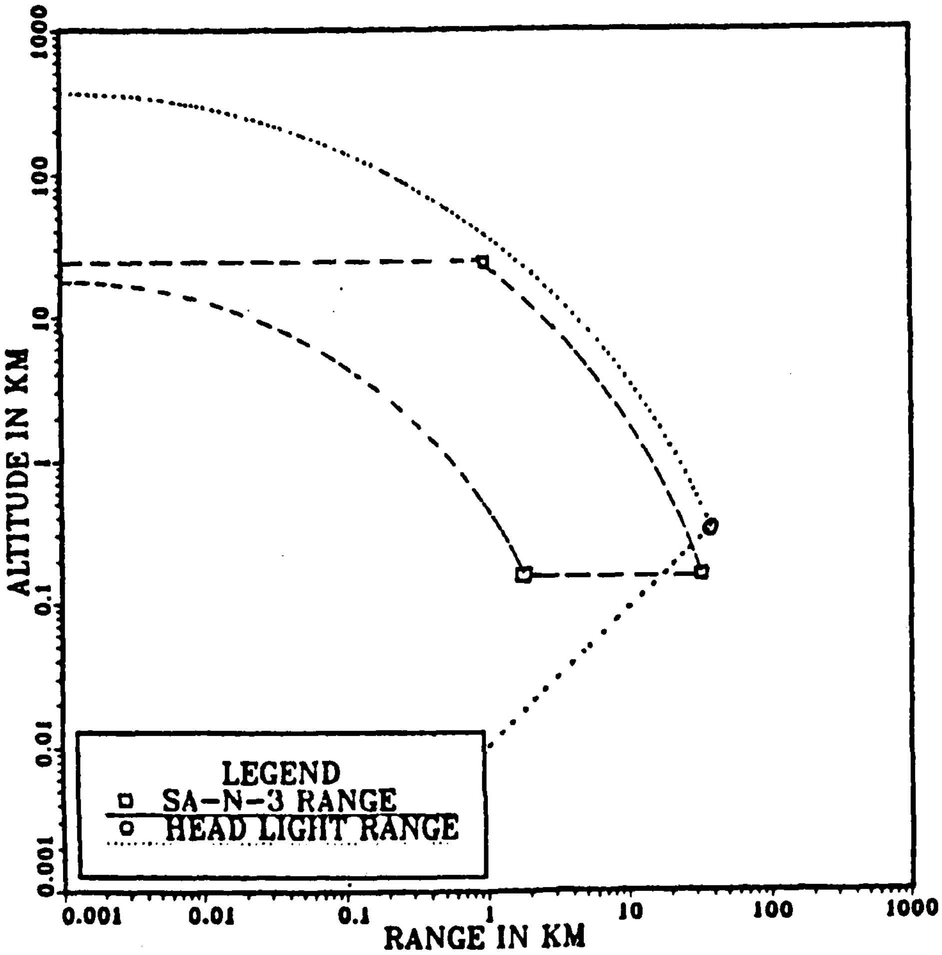

Figure 9.3 Comparison of SA-N-3 Missile and Head Light Group Fire Control Radar.

The Soviet Navy ships fitted with the SA-N-4 missile are: [Ref. 11]

1. 2 Kirov Class with two twin (dual) arm launchers with a magazine capacity for 20 missiles, total 40 missiles stored.

2. 4 Kiev Class with two twin (dual) arm launchers with a magazine capacity for 20 missiles, total 40 missiles stored.
3. 7 Kara Class with two twin (dual) arm launchers with a magazine capacity for 20 missiles, total 40 missiles stored.
4. 2 Sverdlov Class with two twin (dual) arm launchers with a magazine capacity for 20 missiles, total 40 missiles.
5. 21 Krivak I Class with two twin (dual) arm launchers with a magazine capacity for 20 missiles, total 40 missiles stored.
6. 11 Krivak II Class with two twin (dual) arm launchers with a magazine capacity for 20 missiles, total 40 missile stored.
7. 1 Koni Class with one twin (dual) arm launcher with a magazine capacity for 20 missiles.
8. 15 Grisha I Class with one twin (dual) arm launcher with a magazine capacity for 20 missiles.
9. 31 Grisha II Class with one twin (dual) arm launcher with a magazine capacity for 20 missiles.
10. 11 Nanuchka I Class with one twin (dual) arm launcher with a magazine capacity for 20 missiles.
11. 6 Nanuchka II Class with one twin (dual) arm launcher with a magazine capacity for 20 missiles.

12. 1 Sarancha Class with one twin (dual) arm launcher with a magazine capacity for 20 missiles.

13. 3 Slava Class strike cruiser with two twin (dual) arm launchers with a magazine capacity for 20 missiles, total 40 missiles stored [Ref. 11: p. 522], [Ref. 54: p. 148].

The SA-N-4 missile's console:

A twin (dual) arm launcher with 2 SA-N-4 missiles ready to fire and a rapid reloaded magazine capacity for 20 missiles.

Types of radar required for the SA-N-4 missile: [Ref. 11]

Surveillance radar.

Type: Air search radar[36]
Surface search radar[37]

Tracking radar.

Type: Pop Group missile control radar

Description: The Pop Group is the missile fire control radar. Operating frequencies are in G/H-band for target search by a 2 m. parabolic antenna. Pop Group's tracking radar is approximately 8 ft. in diameter with 13-15 GHz J-band system and has an antenna gain of about 48 dB. This tracking radar could serve as the missile beacon receiver. On each side

[36]Top Trough air search radar on Sverdlov Class (Admiral Senyavin (CC) and Zhdanov (CC) or Top Pair air search radar.

[37]Low Sieve on Sverdlov Class.

of the tracking radar are the command guideance groups which both command and guide the SA-N-4 missiles. This I/J-band system operates between 13 to 15 GHz and has typical antenna gain of about 42 dB. [Ref. 49: p. 264]

Launch Weight. [Ref. 14]

419 lb (190 kg)

2. Propulsion

Solid fuel rocket motor

3. Warhead Section

Type of Warhead: [Ref. 48: p. 359]

Conventional warhead

Weight of Warhead: [Ref. 24: p. 122]

90 - 110 lb (40 - 50 kg)

Fuze System: [Ref. 24: p. 122], [Ref. 53: p. 187]

Proximity and impact fuze

Damage Mechanism:

no information available

Explosive Type:

High Explosive (HE) warhead

4. Target Detecting, Tracking, and Missile Guidance

The missile has a radio-command with proportional navigation guidance system. The engagement event begins when the ship's surveillance radar or surface search radar detects all the approaching targets and measures the incoming target velocity, bearing. The data from the search radar is passed on to the Pop Group computer-controlled tracker which commands the launcher to pick up the missile, slews the trackers to the correct bearing, and commences a search leading to target acquisition and lock on. The twin (dual) arm launcher is instructed by the data handling computer to point toward the target, after which the system is ready to fire after tracker allocation.

When the SA-N-4 is launched, the Pop Group missile fire control radar tracks the target and the missile. During flight, the fire control system determines the missile flight path, compares this computed flight path with the predicted flight path of the missile based on current tracking information, determines the correction signals required to move the missile control surfaces to change the current flight path to the new one until it reaches the proper distance. The 50 kg warhead is detonated by the proximity fuze and impact fuze.

Type of Guidance: [Ref. 24: p. 122]

Radio command guidance

Type of Navigation: [Ref. 24: p. 122], [Ref. 51]

Proportional Navigation

5. Performance

Speed: [Ref. 24: p. 122]

acceleration 20-g

Minimum/Maximum Range: [Ref. 53: p. 187]

50 - 15,000 m with slant range 12,000 m

Minimum/Maximum Altitude: [Ref. 19]

30 - 10,000 ft (10 - 3,300 m)

Target Maneuverability:

no information available

Target Destructibility:

no information available

SA-N-4 vs Pop Group

Tracking in J-band (15 GHz), λ = 0.02 m
Antenna diameter, d = 2.44 m
Antenna area, A = 4.67 sq.m
Antenna gain, G = 48 dB
Effective antenna, A_e = 2.0 sq.m

Assume:

Receiver bandwidth, B = 1 MHz
Noise figure, F = 5.38 dB = 3.45 (from fig. 2.3)
$(S_o/N_o)_{min}$ = 14.7 dB = 29.51
From equation 2.16; $S_{min} = 4.07 \times 10^{-13}$ watts

Assume:

For a target cross section 1 sq.m, n = 30, and
Ls = 20
Average power, P_t = 1.5 KW

From equation 2.18; R_{max} = 37 km

Fig. 9.4 shows the maximum radar range and the maximum and minimum missile range versus target altitude.

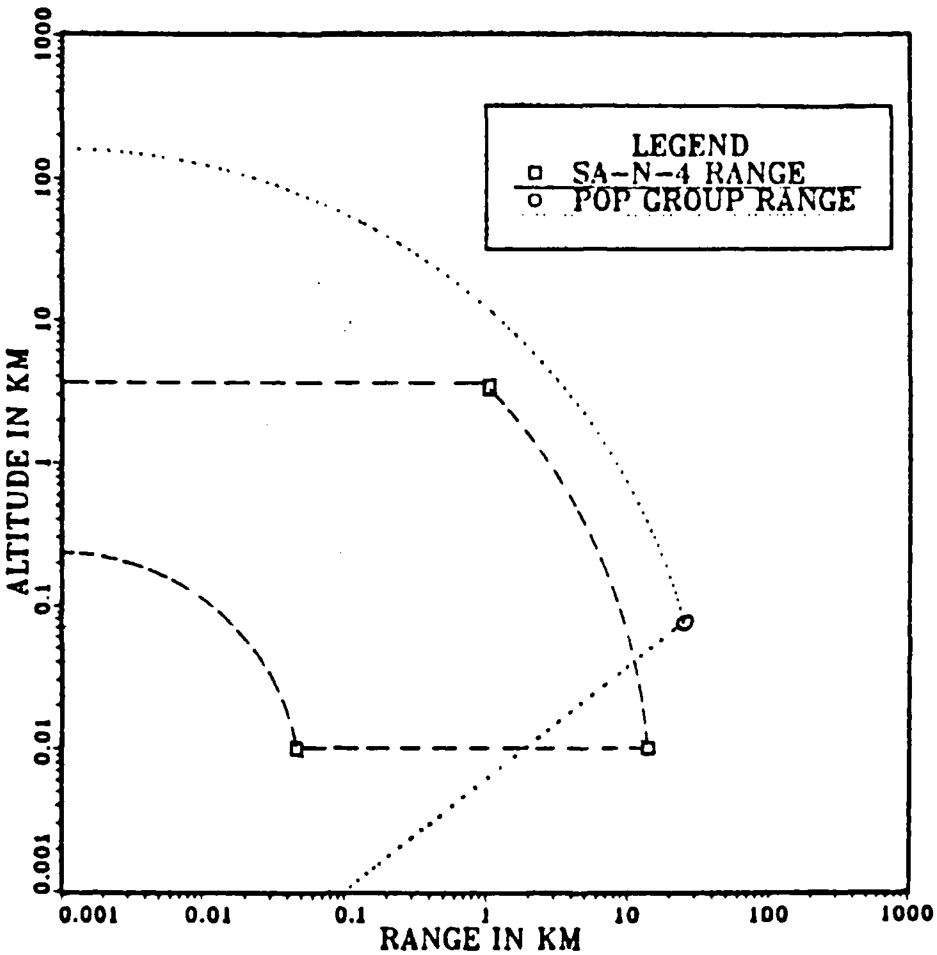

Figure 9.4 Comparison of SA-N-4 Missile and Pop Group Fire Control Radar.

E. SA-N-5

The SA-N-5 is a short-range (10.36 km) surface-to-air missile. It is derived from the land-based SA-7 Grail missile and is fitted on some Osa Class guided-missile patrol boats, some Polnochny Class landing ships, and some auxilary ships. The SA-N-5 is a passive infra-red homing guidance system with a 2.5-kg warhead weight and detonation by graze and impact fuze.

1. Physical Description

Dimensions. [Ref. 14]

Length: 53.25 in (1.35 m)

Diameter: 2.75 in (70.0 mm)

Span: small canard stabilizing fins

System.

Launchers: [Ref. 11]

A quadruple rounds and twin (dual) rounds launcher.

The Soviet Navy ships fitted with the SA-N-5 missile are:

1. Osa I Class with one quadruple rounds launcher with eight missiles.
2. Osa II Class with one quadruple rounds launcher with eight missiles.
3. 2 T 58/AGR Class with two quadruple rounds launcher with 8 SA-N-5 missiles ready to fire.
4. Tarantul I Class with one quadruple rounds launcher.

A target cross section 1 sq.m, n = 30, and

Ls = 20

Average power, P_t = 1.5 KW

From equation 2.16; $S_{min} = 4.07 \times 10^{-13}$ watts

From equation 2.18; R_{max} = 52 km

Fig. 9.6 shows the maximum radar range and the maximum and minimum missile range versus target altitude.

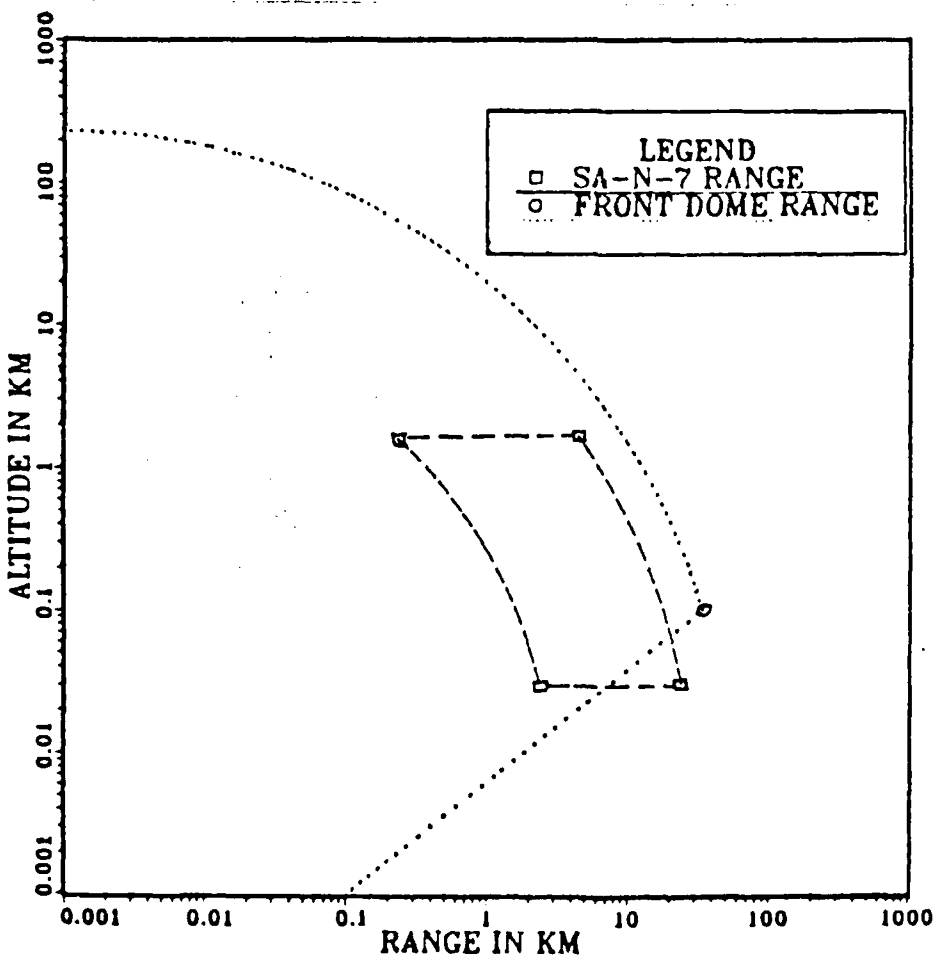

Figure 9.6 Comparison of SA-N-7 Missile and Front Dome Fire Control Radar.

Type of Guidance: [Ref. 7: p. 103]

Semi-active radar homing (SARH)

Type of Navigation:

no information available

5. Performance

Speed: [Ref. 7: p. 815], [Ref. 51]

Mach 3.0

Minimum/Maximum Range: [Ref. 7: p. 815], [Ref. 48: p. 360]

9,900 - 92,400 ft (3,000 - 28,000 m)

Minimum/Maximum Altitude: [Ref. 7: p. 103], [Ref. 51]

100 - 46,000 ft (30 - 14,000 m)

Target Maneuverability:

no information available

Target Destructibility:

no information available

SA-N-7 vs Front Dome

Assume:

Tracking in J-band (15 GHz), $\lambda = 0.02$ m
Antenna diameter, $d = 2.44$ m
Antenna area, $A = 4.67$ sq.m
Receiver bandwidth, $B = 1$ MHz
Noise figure, $F = 5.38$ dB $= 3.45$ (from fig. 2.3)
$(S_o/N_o)_{min} = 14.7$ dB $= 29.51$
Antenna efficiency, $\rho = 0.85$, $A_e = 3.97$ sq.m

2. Propulsion

Dual thrust solid booster and sustainer [Ref. 48: p. 360].

3. Warhead Section

Type of Warhead: [Ref. 6: p. 184]

Fragmentation warhead

Weight of Warhead:

4.0 lb (1.8 kg) [Ref. 6: p. 184]

Fuze System:

Presumably proximity fuze

Damage Mechanism:

a large number of fragments

Explosive Type:

High Explosive (HE) warhead

4. Target Detecting, Tracking, and Missile Guidance

The missile has semi-active radar homing guidance system. After the incoming targets are detected by the air surveillance radar, Top Steer group radar, the information on the targets is passed to the Front Dome missile director radar groups. When the target tracking begins, the data and firing commands are relayed to the proper twin (dual) arm launcher. The SA-N-7 is launched when the targets come into the engagement range. The Front Dome radar groups simultaneously engage multi-targets and salvo the missiles to the single target using different command frequencies.

Systems.

Launchers: [Ref. 7: pp. 103-104], [Ref. 48: p. 306]

A twin (dual) arm launcher.

The Soviet Navy ships fitted with the SA-N-7 missile are: [Ref. 7: pp. 103-104], [Ref. 48: p. 360]

1. 7 Sovremenny Class with two twin (dual) arm launchers.
2. Provorny modified Kashin Class with one twin (dual) arm launcher.

The SA-N-7 missile's console:

A twin (dual) arm launcher which has commanded control from Front Dome missile control system.

Types of radar required for the SA-N-7 missile: [Ref. 7: p. 103]

Surveillance radar.

Type: Top Steer 3-D surveillance radar

Tracking radar.

Type: Front Dome missile control radar[43]

Launch Weight.

23.3 lb (10.6 kg) [Ref. 6: p. 184]

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[43]Six Front Dome for Sovremenny Class and eight Front Dome for Provorny (modified Kashin Class).

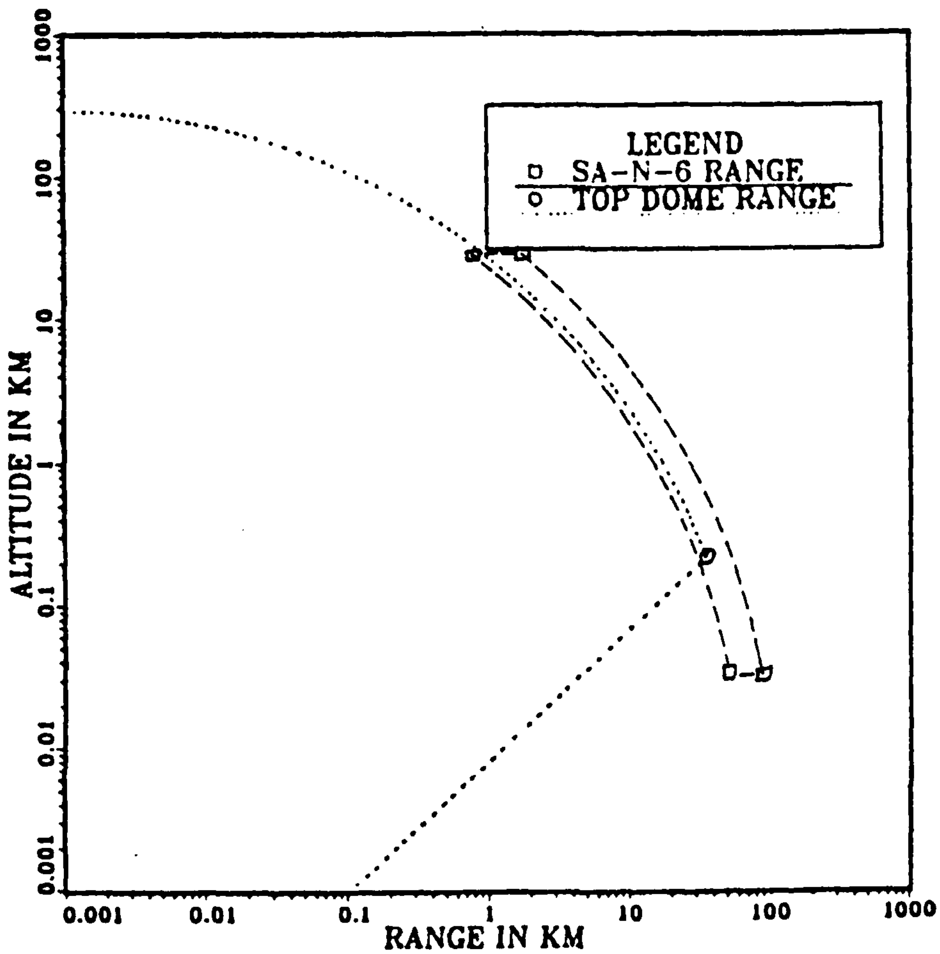

Figure 9.5 Comparison of SA-N-6 Missile and Top Dome Fire Control Radar.

1. Physical Description

Dimensions. [Ref. 15]

Length: 18.4 ft (5.60 m)

Diameter: 1.32 ft (402.30 mm)

Target Destructibility:

no information available

SA-N-6 vs Top Dome

Assume:

Tracking in J-band (15 GHz), $\lambda = 0.02$ m

Antenna diameter, d = 2.44 m

Antenna area, A = 4.67 sq.m

Receiver bandwidth, B = 1 MHz

Noise figure, F = 5.38 dB = 3.45 (from fig. 2.3)

$(S_o/N_o)_{min}$ = 14.7 dB = 29.51

Antenna efficiency, ρ = 0.85, A_e = 3.97 sq.m

A target cross section 1 sq.m, n = 30, and

Ls = 20

Average power, P_t = 5 KW

From equation 2.16; $S_{min} = 4.07 \times 10^{-13}$ watts

From equation 2.18; R_{max} = 70 km

Fig. 9.5 shows the maximum radar range and the maximum and minimum missile range versus target altitude.

G. SA-N-7

The SA-N-7 is a naval air-defence weapon system equivalent to the land-based SA-11 air defence missile, which is described as a low-to medium-altitude weapon with a range of about 28 km, a speed of Mach 3.0, and an altitude capability of 30 to 14,000 m [Ref. 7: p. 103]. Since the SA-N-7 is designed to cope with multiple targets by using in combination six or eight fire control/target illuminating radars, Front Dome, each rail launcher must be capable of rapid firing and reloading.

appropriate guidance commands which are sent to the missile on a data link.

When the SA-N-6 missile reaches the terminal phase, the guidance system is switched to active homing. In active homing the target is detected by electronic radiation equipment in the missile. The active radar homing system uses a radar transmitter located on the missile to illuminate the target, and then uses the radar reflections from the target for guidance.

Type of Guidance: [Ref. 48: p. 360]

Track-via-missile (TVM) in midcourse and active radar homing in terminal course

Type of Navigation:

no information available

5. <u>Performance</u>

Speed: [Ref. 7: p. 102], [Ref. 11], [Ref. 49: p. 266]

Mach 6.0 and acceleration about 100-g

Minimum/Maximum Range:

min. 35 nmi (64 km) [Ref. 11].
max. 60 nmi (111 km) [Ref. 54: p. 150].

Minimum/Maximum Altitude: [Ref. 7: p. 102], [Ref. 11], [Ref. 49: p. 266]

100 - 100,000 ft (30 - 30,000 m)

Target Maneuverability:

no information available

Fuze System:

Presumably active Proximity fuze.[42]

Damage Mechanism:

no information available

Explosive Type:

High Explosive (HE) warhead

4. Target Detecting, Tracking, and Missile Guidance

The missile utilizes the track-via-missile (TVM) guidance system. The operation of the system probably begins when incoming targets are detected by either passive means or the Top Pair radar group. Targets are designated to either of the Top Dome director groups which are then laid on to the necessary threat direction. After the Top Dome radar (or passive detection system) has acquired and locked on to the target, and the target has reached an appropriate engagement range, one or more SA-N-6 missiles are launched in the proper direction, then automatic guidance to interception takes place.

The radar tracking system of the Top Dome group simultaneously tracks both the targets and the missiles as in command guidance. However, in TVM the target tracking beam also serves as the target illuminator, and a receiver on the missile detects the reflected illumination as in semi-active homing guidance. The information on the relative target angular position gathered by the missile is relayed to the control unit on the ship. The guidance equipment processes the echo from the target and the information on target position from the missile, then determines

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[42]By assuming a terminal active homing system.

Types of radar required for the SA-N-6 missile: [Ref. 7: pp. 101-102], [Ref. 54: pp. 149-150]

Surveillance radar.

Type: Top Pair air search radar
Top Steer air search radar

Tracking radar.

Type: Top Dome director group radar

Description: Top Dome is a complex of radar systems incoorperating a number of different antenna elements. There are 2 Top Dome radar director groups on the ship, fore and aft. It embodies long-range tracking which serves to track both targets and missiles and provide guidance functions.

Launch Weight. [Ref. 14: p. 164]

3,300 lb (550 kg)

2. Propulsion

Solid-fuel rocket

3. Warhead Section

Type of Warhead:

no information available

Weight of Warhead: [Ref. 7: p. 102], [Ref. 51]

200 lb (90 kg)

land-based missile. The SA-N-6 missile is estimated to have an operating ceiling of at least 30,000 m, a range of up to 110,000 m at the speed of Mach 6.0 while carrying a 90-kg warhead.

1. Physical Description

Dimensions. [Ref. 14: p. 164], [Ref. 48: p. 360]

Length: 23.0 ft (7.0 m)

Diameter: 17.75 in (450.0 mm)

Span: no information available

Systems.

Launchers: [Ref. 54: p. 148]

A 8-cylinder vertical launcher.

The Soviet Navy ships fitted with the SA-N-6 missile are: [Ref. 11: p. 522], [Ref. 54: p. 148]

1. 3 Slava Class strike cruiser with eight SA-N-6 launchers, total 64 missiles stored.
2. 2 Kirov Class with twelve SA-N-6 launchers.
3. 3 Krasina Class with SA-N-6 launcher.[41]

The SA-N-6 missile's console:

An eight cylindrical-vertical launcher with command control from Top Dome fire control radar.

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[41]No detail in number of launcher.

5. Performance

Speed: [Ref. 14]

Mach 2.5

Minimum/Maximum Range:

min. 0.5 nmi (930 m) [Ref. 52: p. 58].
max. 5.6 nmi (10.36 km) [Ref. 48: p. 360].

Minimum/Maximum Altitude: [Ref. 52: p. 58]

50 - 15,000 ft (15 - 4,600 m)

Target Maneuverability: [Ref. 52: p. 58]

The SA-N-5 can engage the target which has maneuvering up to 5-g.

Target Destructibility:

no information available

F. SA-N-6

The SA-N-6 is an air-defence surface-to-air, supersonic, long-range missile system with anti-cruise missile capabilities. The SA-N-6 is vertically launched from a below-deck rotary magazine with a capacity of eight missiles per launcher [Ref. 48: p. 360]. The missile guidance is track-via-missile (TVM) [Ref. 48: p. 360]. Each ship has two such director groups located fore and aft, probably for the purpose of achieving an all-round engagement capacity rather than by any requirement to associate the individual directors with missile launcher installations in specific parts of the ship. The missile was adopted from the SA-10

3. Warhead Section

Type of Warhead: [Ref. 5], [Ref. 55: p. 163]

Fragmentation with smooth casing

Weight of Warhead: [Ref. 51], [Ref. 55: p. 163]

5.5 lb (2.5 kg)

Fuze System: [Ref. 55: p. 163]

Graze and impact fuze

Damage Mechanism:

a large number of fragments

Explosive Type:

High Explosive (HE) warhead

4. Target Detecting, Tracking, and Missile Guidance

Target designation may be performed by air search radar or naval (surface search) radar. The SA-N-5 missile has to lock on its target at considerable distances before homing into the target for the midcourse phase, then reverting to passive IR homing in the terminal phase which the missile homes in (close to) on heat generated by the target. The SA-N-5 missile has a proximity fuze which causes the warhead detonation by graze or impact fuze.

Type of Guidance: [Ref. 52], [Ref. 55: p. 163]

Passive infra-red (IR) homing

Type of Navigation:

no information available

15. 1 Primorye Class with one quadruple rounds launchers with 8 SA-N-5 missiles stored.

The SA-N-5 missile's console:

Mostly a quadruple rounds launcher with 4 SA-N-5 missiles ready to fire, and presumably, a magazine capacity for 8 missiles. The launcher has the *command control from* fire control system.

Types of radar required for the SA-N-5 missile: [Ref. 11]

Surveillance radar.

Type: Big Net air search radar
Strut Curve air search radar
Band Stand[39] naval radar
Square Tie[40] naval radar

Tracking radar

Type: No information available

Launch Weight. [Ref. 7], [Ref. 14]

20.3 lb (9.2 kg)

2. <u>Propulsion</u>

Solid propellant rocket booster and sustainer [Ref. 48: p. 360], [Ref. 55: p. 163]

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[39]For Tarantul Class

[40]For Osa *I* & *II* Class

5. 1 Tarantul II Class with one quadruple rounds launcher.
6. 12 Pauk Class with one quadruple rounds launcher with 8 SA-N-5 missiles stored.
7. 2 Ropucha Class with four quadruple rounds launcher with 32 SA-N-5 missiles stored.
8. Alligator Class[38] with three twin (dual) rounds launchers with 24 SA-N-5 missiles stored.
9. Polnochny Class Type A with two quadruple rounds launchers with 16 SA-N-5 missiles stored.
10. Polnochny Class Type B & C with four quadruple rounds launchers with 36 SA-N-5 missiles stored.
11. Ugra Class with two quadruple rounds launchers with 16 SA-N-5 missiles stored.
12. 7 Lama Class with four quadruple rounds launchers with 32 SA-N-5 missiles stored
13. 3 Balzam Class with two quadruple rounds launchers with 16 SA-N-5 missiles stored.
14. 5 Primorye Class with two quadruple rounds launchers with 16 SA-N-5 missiles stored.

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[38]The SA-N-5 missile fitted in some ships and only Petr Llichev fitted with two twin (dual) rounds launchers with 12 missiles stored.

TABLE 9

Comparison of the Missile Specifications in the Soviet Navy

Missile	Dimension			Propulsion	Guidance		Launch Weight	Warhead		Speed	Ranje		Intercept		Remarks
	L m	Dia mm	Span mm		Guid-dance	Navig ation	(kg)	Weight kg	Type	Mach	Min m	Max m	Min m	Max m	
SA-N-1	5.9	700	1220	Solid fuel rocket with tandem solid fuel booster	SARH	-	400	60	Convention	2.0	2700	35000	300	15000	slant range 28.0 km
SA-N-2	10.7	660.4	2230	solid prop. booster and sustainer	Radio comma-nd gu-idance	-	2300	130	Frag. with int-ernally casing	3.5	-	48000	30	24400	slant range 40 km
SA-N-3	6.20	335	1500	Ramjet with solid fuel booster	SARH	CLOS	550	80	Fragmenta-tion	3.0	4000	59000	150	25000	
SA-N-4	3.2	210	640	Solid fuel rocket motor	Radio comm.	Prop. Nav.	190	40-50	Convention	acc.-20-g	50	15000	10	3300	slant range 1[illegible] km
SA-N-5	1.35	70	-	Solid prop. booster and sustainer	Passi-ve IR homing	-	9.2	2.5	Frag. with smoo-thcasing	2.5	930	10360	15	4600	
SA-N-6	7.0	450	-	Solid fuel rocket motor	TVM in mid. & active in te-rminal	-	550	90	-	6.0	64000	111000	30	30000	
SA-N-7	5.6	402.3	-	Dual-thrust solid boost. and sust.	SARH	-	10.6	1.8	Fragmenta-tion	3.0	3000	28000	30	14000	

X. THE ROYAL NAVY'S AIR DEFENSE SYSTEMS IN THE FALKLANDS CONFLICT

A. INTRODUCTION

The 43 day Falklands war from the Argentine invasion on 2 April 1982 to their surrender at Port Stanley on 14 June 1982 was the first significant [Ref. 56], evenly-matched naval combat to occur since the Second World War. This study examines the Falklands war in the area of shipborne air defense. The air war of the Falklands clearly demonstrates at least one thing to all; modern weaponary can enable even minor world powers to pack a powerful military punch. Air forces and modern, sophisticated weaponary represent the key to established this "new" source of national power.

B. SHIPBORNE WEAPONS SYSTEMS PERFORMANCES

British and Argentinian surface warships never engaged each other directly during the Falklands Conflict. It appears that the Royal Navy's shipborne defenses were unable to completely contend with the Argentina air raids, based on the loss of six modern ships and some damages throughout the Falklands Conflict. The British task force provided air defense against the Argentine aircraft and for assualt land-based troops. When the troops were put ashore, destroyers and frigates of the task force remained behind in the narrow confines of the Falkland Sound in order to help protect and support the landing force with their missiles and gunfire. Accordingly, a review of the capabilities and performance of the shipborne weapons systems of the Royal Navy in the Falklands is in order.

1. Missile Systems

Missile systems were utilized extensively throughout the Falklands Conflict in a conscious effort to increase their deterrent effect.

a. Sea Dart

Sea Dart is an area air defense weapon deployed on warships of the Royal Navy; Invisible Class, Type 82, and Type 42. The Sea Dart is capable of being fired in an anti-ship, and allegedly, anti-missile mode. The missile has a speed of Mach 3.5, and it can intercept the target at a range up to 50 km and with a ceiling of 30 - 25,000 meters. However, during the Falklands Conflict, Sea Dart's performance acted as a considerable inhibitor to medium level and high level attacks, but was relatively useless for the low level flight adopted by the Argentine pilots that caused the loss of H.M.S. Sheffield and H.M.S. Coventry - the Type 42 destroyers [Ref. 57]. Although the kill figures indicate that Sea Dart was the most successful shipborne weapons systems in the Falklands war, having achieved eight kills [Ref. 57], two ships using Sea Dart were killed:

The Sheffield, a type 42 class destroyer, had been criticized for its lack of both offensive and defensive capabilities. It carried only one 4.5 inch gun, one twin (dual) arm Sea Dart launcher, one Lynx helicopter and two 20 mm anti-aircraft guns [Ref. 11]. In addition, the Sheffield lacked advanced eletronic warfare equipment, anti-missile missiles and a close-in-weapons-system (CIWS) capable of detecting and destroying in-bound hostile missiles. On the 4th of May, an Argentine pilot flying the Super Entendard so low an approach profile that the Sheffield's shipborne radar simply could not detect the raid launched the AM-39 Exocet missile. There were twenty seconds from time of initial

detection of the missile until impact of the missile. During that time no jamming chaff rocket was launched, despite the fact that chaff was known to be an effective countermeasure against the Exocet missile. On balance, several factors contributed to the loss of the H.M.S. Sheffield. The lack of airborne early warning assets, the absence of protective air cover for the surface radar pickets, and the lack of a terminal self defense capability against missile threats on the platform. The Sea Dart was not designed to simultaneously engage many targets due to insufficient capability of the automatic rapid loading system which is another contribution to loss of the H.M.S. Coventry, the type 42 class destroyer on the 25th of May. Coventry was not alone at her remote radar picket station. Accompanying her was H.M.S. Broadsword. As the attack commenced, the Argentine pilots approach on the two picket vessels, H.M.S. Coventry and H.M.S. Broadsword. Coventry could not have contended with four A-4 aircrafts for any one of several reasons. First of all, her Sea Dart missile system was not designed to engage so many targets simultaneously. Secondly, Coventry's automatic missile loading system had experienced a malfunction which further degraded its performance capabilities. Thirdly, Sea Dart was shown to be relatively useless against very low flying target in the Falklands war. After Coventry had succeeded in destroying two of the attacking Skyhawks with two Sea Dart missiles, the third attacker finally manage to score a direct hit on the ship. [Ref. 56], [Ref. 35]

b. Seawolf

Seawolf is a missile used in the Royal Navy's short-range, self-defense system, GWS 25. The system is designed to provide rapid reaction defense against both aircraft and sea-skimming missiles. Throughout the heat of

the Falklands combat, Seawolf proved to be a capable and flexible weapons system. Only Brilliant and Broadsword, the type 22 destroyers were Seawolf equiped.

In the Falklands combat, Argentine low altitude tactics necessitated increased reliance upon the television guidance of Seawolf missiles, which revealed one more operational problem. Up to then, there were two operational problems in shipborne air defense regarding the Seawolf missile.

1. The Seawolf missile is a self defense system. During the combat on the 25th of May, the loss of H.M.S. Coventry occurred. The Argentine air commanders formulated a preliminary, coordinated, multi-directional strike against the Royal Navy's covering force, with special attention being given to radar pickets, but the Seawolf's ships were to be avoided. In the flight of nine Skyhawks and Mirage aircraft that was assigned to attack the task force on that day, six were dedicated to attacks on the radar pickets, Broadsword and Coventry. As the attackers commenced their approach on the picket vessels, they avoided H.M.S. Broadsword, which was equiped with the Seawolf, and concentrated instead on the H.M.S. Coventry, which was not equipped with the Seawolf missiles. [Ref. 57]
2. The television guidance system against low flying missiles. During optical engagements against sea-skimming missiles, operators found that the flare on the missiles rear was so bright that it could obscure the target aircraft itself. However, the Seawolf navigation was modified by Marconi engineers with the task force so that Seawolf flew slightly off the operator's line of sight until the last few seconds of an engagement [Ref. 35].

Seawolf is credited with downing five Argentine aircraft [Ref. 35]. Nevertheless, both Brilliant and Broadsword were damaged by bombs which failed to explode.

c. Seacat

Seacat is a close-range (500 - 5,000 m) guided missile for anti-air defense which may also be used against surface targets within 500 - 7,000 m range. Three different installations of the subsonic Short's Seacat, Plymount, Fearless, Exeter apparently were used in the South Atlantic, ranging from full intergration with ship's radar and control to basic optical. Information regarding the employment of the Seacat missile in the Falklands combat is extremely sparse. Apparently, the Seacat performance had a deterrent effect on Argentine pilots, causing several to break off engagements. Three Seacat installations in the Falklands have been credited with destroying six Argentine aircraft [Ref. 57], [Ref. 35].

2. Gun Systems

The Royal Navy's naval gunnery systems in the Falklands war consisted of the Vickers 4.5-inch gun, although some ships are also fitted with 20 or 40 mm anti-aircraft guns. The Falklands demonstrated a continued need for naval gunnery in supporting ground offensive operation and augmenting anti-air warfare defenses. The Type 21 frigate H.M.S. Avenger claimed an aircraft shot down with her Mk8 4.5 inch gun [Ref. 59].

C. CONCLUSION

Intensive air-sea combat around the Falkland Islands ended with an estimated 109 combat aircraft [Ref. 58] of the Argentine Air Force and Navy destroyed by the Royal Navy's

missiles and aircraft. The outcome of the conflict reflects the strengths and weakness of both combatants, particularly the Royal Navy, one of the North Atlantic Treaty Organization's most powerful members. The following comments have been made:

1. Lack of airborne early warning (AEW) radar aircraft forced the Royal Navy to station radar picket ships away from the main fleet and around the beachhead area, where they were alone and vulnerable to the Argentine air force. Four warships, Sheffield, Ardent, Antelope, and Coventry, were lost during radar picket duties.
2. Lack of a long or medium range air-to-air missile prevented the Royal Navy from striking at Argentine incoming raids well away from the defensive rings established around the fleet and beachhead. The longest range missile carried by the task force's Sea Harrier fighters was the AIM-9L Sidewider which has maximum range of 11 mi (17.7 km).
3. Close-in-weapons-systems deployed on warships were insufficient in number to be effective. Only two of the original ships in the Royal Navy task force were equipped with the Seawolf missile, and none of the large ships had equipment capable of countering sea-skimming missiles or low flying aircraft at close range.
4. Lack of a supersonic interceptor had prevented interceptions from being carried out in the 400 mile channel between the Argentine mainland and the Falkland Islands. The fighter used throughout the war was the Harrier/Sea Harrier.
5. Cargo ships lacked an effective air defence system. During the war, the British did equip some requisitioned merchant vessels with some limited military

capabilities. Unfortunately, these capabilities did not provide any actual self-defense capabilities. The luckless Atlantic Conveyer was lost due to this fact.

6. Lack of a long range surface-to-air missile deployed on warships made it difficult to protect the task force ships. The longest missile was Sea Dart which has lethal radius 50 km and ceiling 30 - 25,000 meters.

Finally, Seven of some one-hundred ships that comprised the Royal Navy South Atlantic Task Force were sunk in the Falklands War. And at least eight were significantly damaged.

The seven ships destroyed were: [Ref. 56], [Ref. 57]

1. H.M.S. Sheffield (Type 42 destroyer) in 4 May 1982.
2. H.M.S. Ardent (Type 21 frigate) in 21 May 1982.
3. H.M.S. Antelope (Type 21 frigate) in 23 May 1982.
4. H.M.S. Coventry (Type 42 destroyer) in 25 May 1982.
5. Atlantic Conveyer in 25 May 1982.
6. Sir Galahad (logistic landing ship) in 8 June 1982.
7. Sir Tristram (logistic landing ship) in 8 June 1982.

The eight ships significantly damaged were: [Ref. 56], [Ref. 57]

1. H.M.S. Glasgow (Type 42 destroyer) in 12 May 1982.
2. H.M.S. Broadsword (Type 22 frigate) in 21 and 25 May 1982.
3. H.M.S. Brilliant (Type 22 frigate) in 21 May 1982.
4. H.M.S. Antrim (County-class destroyer) in 21 May 1982.
5. H.M.S. Argonaut (Leander-class frigate) in 21 May 1982.
6. Sir Lancelot (logistic landing ship) in 24 May 1982.
7. H.M.S. Plymouth (Type 12 frigate) in 8 June 1982.

8. H.M.S. Glamorgan (County-class destroyer) in 11 June 1982.

XI. SUMMARY

This thesis has examined thirty-one of the world's naval SAM systems. In general, they work in the following way. The shipborne surface-to-air missile system detects the target using the ship's surveillance radar. The target information (range, bearing, elevation, course, and speed) is passed to the Weapons Direction System for evaluation with respect to the availability of the missile system and the capability of that system. When this phase is completed, the target is designated to a fire control system (FCS) for acquisition and tracking. While the fire control system tracks the target and solves the fire control problem, a launcher is assigned and the missiles are loaded. When the target is within range of the weapon, the missile is launched. With everything functioning properly, the target will be destroyed.

The shipborne surface-to-air missiles can be divided into two categories: area defense and point defense.

Area Defense. An area defense system is basically fitted with long-range SAMs and the missile carrying ships are stationed around the valuable ships, such as an aircraft carrier, or around a convoy. Area defense at sea includes not only defense against conventional air attack, but also, perhaps much more important these days, defense against anti-ship missiles, whether they are launched from ships or from aircraft. Some of the area defense missiles are Standard SM2-ER, Masurca, Sea Dart, and SA-N-3. These missiles have a maximum range that varies from about 30 km to about 120 km, i.e. the missiles are considered in medium range to long range. Most of the long-range missiles use different type of guidance for the midcourse and the

terminal phase. For example, the Standard SM2-ER and the SA-N-3 use command guidance in the midcourse phase and semi-active radar guidance in the terminal phase. Some medium-range missiles use the same types of guidance as the long-range missiles, and some use one type all-the-way. For example, the SA-N-1 uses radio command guidance in the mid-course phase and semi-active radar homing guidance in the terminal phase. The Sea Dart uses semi-active radar homing all-the-way. The modern long-range missiles should have accurate guidance, be resist to jamming, and have a high single kill probability. The system should have rapid, automatic, and simultaneous capabilities of tracking several targets, automatic reloading and be able to launch the missile in all directions.

Point Defense. Point defense means defense of one's own ship. A point defense weapon is for use against an aircraft which is obviously attacking the ship, including stand-off, low-flying anti-ship missiles. Point defense missiles must have a very rapid reaction time because the interval between detecting an approaching missile, particularly at low level, and launching the missile may be very short. For example, the Albatros system can launch the Aspide missile within a 2.5 second interval. The missile launcher must also be capable of very rapid slewing. Ranges of point defense missiles vary. The Royal Navy has the SLAM, Seacat, and Seawolf with a maximum range of 3, 5, and 25 km and a missile weighing 11, 65, and 82 kg respectively. The French Navy uses the Satcp and Naval Crotale, with a maximum range of 6 and 11 km and a missile weighing 20 and 80 kg respectively. Crotale's launcher carries eight missiles. The US Navy has the Sea Sparrow with a maximum range of 25 km and a missile launch weight of 220 kg, over three times that of the Seacat. Eight Sea Sparrows are carried on one launcher in the US version. In the NATO version, although eight

missiles are still carried, the missiles themselves are smaller and the launcher therefore lighter and more suited to the smaller NATO European ships. The Soviet Navy has the SA-N-4, SA-N-5, and SA-N-7 with a maximum range of 15, 10, and 28 km and a missile launch weight of 190, 9.2, and 10.6 kg respectively. The Point Defense missile usually uses one type of guidance. The new directors should have capabilities of tracking several targets at one time. The system should engage simultaneous targets, thus shifting the stress to the launcher, the magazine, and the loading system to keep up with firing orders.

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